

THE CERAMIC RESOURCES OF SOUTH-WESTERN AUSTRALIA.

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INTRODUCTION.

The discovery in 1911 that the vitrified drain pipes required for the newly initiated drainage of Perth would have to be imported at high cost was responsible for the staff of the then Geological Survey Laboratory instituting a research into the ceramic resources of South Western Australia. Inquiries showed that this high cost was due to the fact that the pipes were either imported already made from the Eastern States or were made in Perth out of clays wholly, or almost wholly, imported from Victoria or Tasmania. This seemed quite unnecessary in view of the wide range of clays which had been observed in the State although manufacturers expressed the opinion that no Western Australian clay was suited for vitrified pipe making. The suggestion that if no single clay were suitable, a mixture of two or more clays might be found to serve was unfavourably received. This was a distinct challenge to experimental chemists, which could not be left unanswered, and experiments were immediately inaugurated to prove whether or not it was a fact that no mixture of local clays could be found to yield a satisfactory vitrified pipe.

The requirements for such a mixture were definite. The grain must be fine, the mixture highly plastic, it must give a dense vitrified body at about 1300°C., which would take a salt glaze, the total shrinkage must not be excessive, whilst the colour was unimportant. It was first assumed that a good base would be one of the Collie Coalfield sedimentary shales, many of which are very fine grained, semi-refractory, with low air and fire shrinkage, and of medium plasticity, whilst they are available in very large tonnages. To blend with this it was necessary to find an equally fine grained clay of higher plasticity and containing sufficient iron to flux the more refractory clay and bring its vitrifying temperature to the right point and enable it to take a salt glaze. Such clays were found at several points on the Swan Coastal plain, and experiments were made with one from Belmont obtained in close proximity to existing pipe works. After a number of experiments the following mixture was found to give an excellent body.

Mujar*—pale grey shale	..	..	..	..	60 per cent.
Belmont†—red alluvial clay	..	..	..	..	40 per cent.

This mixture was highly plastic and fine grained, giving, when trial pieces were burnt at 1300°C., a grey well vitrified, extremely dense and tough body, quite impervious to water, even without glazing, and taking a salt glaze well by virtue of its iron content. The air and fire shrinkages were moderate.

* Near Collie.

† Near Perth.

This practical demonstration on a small scale appealed at once to local manufactures and financiers and had immediate results of great importance to the State, viz.:

(1) The permanent establishment of a new factory in Perth for the production of such ware;

(2) The exploitation in large quantities of a mineral previously unutilised;

(3) The material reduction in price of drain pipes, and, therefore of sewerage connections;

(4) It opened the eyes of local ceramic manufacturers for the first time to the practical value of scientific investigation, and the possibility of discovering a suitable mixture of clays for any particular work when no single clay could be found possessing the desired properties.

Later experiments indicated the feasibility of substituting for Belmont clay other coastal-plain clays of similar type, *e.g.*, that from Coolup; and for Mujar shale, similar shales from other parts of the Collie field. Finally freight costs were reduced and working properties improved by adding a third fine plastic clay from Mundijong, capable by itself of vitrifying at about 1300°C.; a suitable mixture being:—

Collie	..	..	..	..	40
Mundijong	..	..	..	..	30
Coolup	..	..	..	..	30

No imported clay has been used since that time in this industry.

From 1911 till 1917 clays continued to be tested in the Geological Survey Laboratory. In the latter year the then Minister for Industries (Mr. R. T. Robinson) was so satisfied with the importance of the work that he suggested a more thorough stocktaking of our ceramic resources and authorised the construction in the laboratory of a small kiln, a potter's wheel and other subsidiary equipment for semi-commercial trials, and the engagement of a practical potter with wide experience to collaborate with the scientific staff in carrying out these trials. Notices were put in the daily and weekly press inviting samples of clay in not less than 10 lb. parcels to be submitted by the public for trial, details being required as to locality, thickness of overburden, probable extent, etc., of the deposit.

In 1918 these investigations were continued with funds supplied partly by the State, partly by the Federal Government through the then Commonwealth Bureau of Science and Industry. Kiln tests were continued up till the middle of 1919 when lack of funds prevented their continuation and the intensive campaign ended, giving place to a renewal of prior conditions with laboratory tests on a small scale on a limited number of new samples. This condition prevails at the present day.

The only use to which the kiln has been put since that date was in 1924 when test pieces were prepared in it for the British Empire Exhibition. For the ceramic exhibition there displayed, bronze medals were awarded in 1924 and 1925. Apart from brief notes in annual departmental reports and a summary of our knowledge of local ceramic materials prepared for publication in an official Mineral Resources Pamphlet, the results of the experiments have never been published. Individual reports, however, have been furnished to persons submitting samples, and all the data, including the test pieces, have been at all times available in the Government Chemical Department, to local manufacturers and other interested parties.

Particular attention was directed during the most active years of the research to the State's resources in white clays, feldspars and other minerals required in the manufacture of white domestic ware which had not, up till then, been produced locally. Subsequent results have shown how successful this was. Abundant supplies were located of true China Clay having properties indistinguishable from the world renowned Cornish clays. Whilst ball clays with the high plasticity of English and United States clays were extremely rare, large deposits were disclosed of a less plastic variety of white clay, to which the term semi-ball clay was given, which could take the place of the usual mixture of ball clay and China Clay.

Of subsidiary minerals, high grade feldspar was located in abundance as well as suitable substitutes for the European flint.

Another line of ware, terra cotta roofing tiles, received attention. The somewhat similar but rougher and more porous flower pots and agricultural drain pipes, had been made without intermission for many years, from alluvial clays in the Swan Valley. Except, however, for a few roofing tiles made in 1901 at Woodbridge, and a few more made in 1904 at Belmont and Bunbury, architects had been driven to use the most unsightly, although efficient material, corrugated iron, for the roofs of all but a few very expensive houses, on which Marseilles tiles were employed. War years brought a great increase in the price of galvanised iron and a shortage of supplies, with the result that a well-known importer of French tiles began to make enquiries in the State as to the possibility of manufacture locally. Full use was made of the information available in the Government Laboratory and in the middle of 1917 the first permanent factory for the manufacture of Marseilles-pattern tiles was established in Perth.

Other experiments, many of them leading to practical results in greater or less measure, had for the object the improvement in quality of local red brick and firebrick, the possibility of manufacturing assay crucibles and scorifiers, as well as sanitary ware, glazed tiles and hard porcelain. These results have been most gratifying. As direct or indirect outcomes of this research, the following may be recorded as particularly noteworthy:—

- (1) The permanent establishment of a vitrified pipe factory;
- (2) An increase and improvement in the manufacture of refractory bricks and blocks of various types;
- (3) The establishment in 1921 of a white ware industry, centred mainly in the Calyx Porcelain Works at Subiaco, where at present a large range of table and other domestic ware of semi-porcelain is produced as well as some vitrified ware and sanitary ware. This was the direct result of a scientific ceramic stocktaking revealing the presence of suitable clays, feldspars and flint substitutes in the South-Western part of the State. Profiting by the information available, a second factory shortly afterwards began to put cream coloured domestic ware on the market.
- (4) The establishment of a permanent roofing tile industry revolutionised the appearance of the newer suburbs of Perth, where terra cotta tiles have almost completely taken the place of corrugated iron on all better class residences.
- (5) The location of the first cement works in the State was assisted materially by the large amount of information available in regard to the chemical and mechanical composition of our alluvial clays.

Although there are now a large number of ceramic industries in the State, and many clay deposits are being worked to supply them, the research must not be looked upon as completed. Well sinking is constantly disclosing fresh deposits of good clays which require listing and recording, for it is now an established fact that rock weathering has extended to a great depth in south-western Australia, and underneath an uninviting lateritic or sandy surface there lie in many places great thicknesses of pure white and other valuable clays whose properties and capacities are well worth testing.

On the other hand, from manufacturers still come such questions as: (1) Where can we get a better substitute for English ball clay than we have at present? (2) cannot we get supplies of suitable felspar nearer to the factories than Coolgardie? (3) how can we overcome the small black specks which appear in our white ware from time to time? (4) what is the best mixture of local materials to make a good electrical porcelain? (5) how can we reduce the high porosity of our red bricks without unduly raising the cost, etc.?

A brief resume of the ceramic industry in Western Australia will not be out of place in this introduction.

Red Brick.—This appears to have been the first clay industry started in Perth, house bricks of yellow to red colour being made from the clay beds lying between St. George's Terrace and the river. This was rather a sandy clay, and whilst some of the bricks have stood well, others have yielded badly to wind erosion. Later the centre of the industry moved to East Perth, then to the Midland Junction district, where a large number of kilns are still in operation. In all cases a rather sandy clay is being used, giving a brick of fair appearance but of high porosity. The oldest houses in Perth can still, in most cases, be recognised by their brickwork, consisting of alternate reddish brown headers, and yellow stretchers. The Town Hall was built of bricks made at what is now Queen's Gardens in East Perth.

In 1903 a great advance was made in brickmaking by the discovery that a pressed brick of excellent colour and finish could be made of a mixture of plastic alluvial clay and ground slate from the soft Precambrian beds of the Armadale district. This discovery was promptly followed by the installation of a Hoffman kiln, and other necessary plant for the production of such bricks. The production still continues and the success of the first plant has been followed by the opening of quarries and erection of similar plants at Byford and Cardup.

Red bricks have also been made at Kelmseott, Bunbury, Albany, Coolgardie, Kalgoorlie, and many other country towns from local alluvial or eluvial clays.

Refractory Brick.—Firebrick and fire-lumps appear to have been first made at Glen Forrest (then known as Smith's Mill) as far back as 1896. Work is still carried on there and a larger quantity of firebrick and miscellaneous mouldings is made from a mixture of completely kaolinised granite and similarly altered epidiorite. Such deposits are of widespread occurrence in the Darling Ranges. In 1900 a second works for the manufacture of refractories was established at Clackline. Here the raw materials used are kaolinised schistose greenstone, kaolinised dolerite and altered sillimanite schist, a kaolinised mica schist and a decomposed pegmatite, all of which

are obtained in the quarries adjacent to the works. In recent years a further plant was established in East Perth, the clays used being of various types from a number of localities in the Darling Ranges.

Many years ago some magnesite bricks were made at Ravensthorpe for use in the copper smelting plant there, but the industry, which was on a very small scale, long since died out.

No silica bricks have ever been made in the State, though such bricks are imported in some quantities, and there are indications that suitable quartzite is obtainable locally,

Domestic White Ware and Cream Coloured Ware.—As already stated none of this was made in the State till 1919, when the Calyx Company started the manufacture of plain white stone-ware, or semi-porcelain table ware. Later a second factory started making similar ware and cream coloured kitchen ware. These industries have advanced until now all kinds of plain and ornamental domestic ware for table, toilet, etc., are produced.

Vitrified Ware.—No fine hard porcelain has yet been made, but a little electrical porcelain has been put on the market. In rougher ware of light colour, acid carboys and ink bottles are made. The main line of vitrified ware made is drain pipes, with smaller amounts of sanitary fittings, telephone conduits and miscellaneous salt glazed ware with similar body.

Terra Cotta Ware.—Complete local supplies of flower pots and porous agricultural drainpipes have been made for many years from the finer and less sandy sedimentary clays of the lower Swan Valley. A few roofing tiles appear to have been made at Bunbury and Guildford fifty years or more ago, but the industry died out. Again in 1901 roofing tiles were made at Woodbridge, sufficient to cover Parliament House. From 1904 onwards shingle tiles have been made in varying quantities at Belmont near Perth, but it was not till 1917 that the manufacture of high-class roofing tiles was begun in earnest. This industry has now reached to important dimensions as explained on a previous page. Architectural terra cotta has been made on a small scale and a good example is to be seen on the face of the Sculpture Gallery in Perth.

CONSTITUENTS OF CLAYS.

No clay is composed of a single chemical compound. On the contrary, even the whitest and purest looking of them is such a heterogeneous mixture, that no two authorities are agreed as to a final definition of the term "clay." In the ultimate analysis, however, it will be found that all clays contain silica and alumina in excess of any other chemical unit and that combined water is an essential constituent. Within the limits expressed by this statement, wide variations are known in the ultimate chemical composition, and still wider variations in the proportions of the several mineral units built up of the simple oxides shown in a chemical analysis. A few of these minerals are present in comparatively large amounts in almost all clays; others are invariably only very minor constituents; others again are sometimes abundant, sometimes rare, or absent altogether. These variations give rise to differences of behaviour in manufacturing processes which are used to define the different types of commercial clays.

In order to understand the behaviour of the mixed clays it is necessary to consider the properties of the individual mineral units. The complete list of minerals believed to occur in clays is as follows:—

Major Constituents—

Kaolinite	...	...	...	...	$\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$
Halloysite	...	...	...	...	$\text{Al}_2\text{O}_3, 2\text{SiO}_2, 4\text{H}_2\text{O}$
Quartz	...	...	...	...	\text{SiO_2
Limonite	...	...	...	...	$\text{Fe}_2\text{O}_3, \text{H}_2\text{O}$
Muscovite	...	...	...	...	$2\text{H}_2\text{O}, \text{K}_2\text{O}, 3\text{Al}_2\text{O}_3, 6\text{SiO}_2$

Minor Constituents—

Salt	...	...	...	...	\text{NaCl
Calcite	...	...	...	...	\text{CaCO_3
Felspar	...	...	...	...	$\text{K}_2\text{O}, \text{Al}_2\text{O}_3, 6\text{SiO}_2$
Chlorite	...	...	...	...	$(2\text{H}_2\text{O}, 2\text{MgO}, \text{Al}_2\text{O}_3, \text{SiO}_2) + (2\text{H}_2\text{O}, 3\text{MgO}, 2\text{SiO}_2)$
Opal	...	...	...	...	$3\text{SiO}_2, \text{H}_2\text{O}$
Gibbsite	...	...	...	...	$\text{Al}_2\text{O}_3, 3\text{H}_2\text{O}$
Humus	...	...	...	...	C, H, O, N, in indefinite proportions
Coal substance	...	...	...	...	C, H, O, N, in indefinite proportions

Constituents rarely, if ever, present in quantities exceeding one per cent.—

Pyrite	...	...	...	...	\text{FeS_2
Rutile, Brookite, Octahedrite	...	...	...	...	\text{TiO_2
Doelterite	...	...	...	...	$\text{TiO}_2, \text{H}_2\text{O}$
Ilmenite	...	...	...	...	\text{FeTiO_3
Siderite	...	...	...	...	\text{FeCO_3
Zircon	...	...	...	...	\text{ZrSiO_4
Gypsum	...	...	...	...	$\text{CaSO}_4, 2\text{H}_2\text{O}$
Alunite	...	...	...	...	$6\text{H}_2\text{O}, \text{K}_2\text{O}, 3\text{Al}_2\text{O}_3, 4\text{SO}_3$

Doubtful Constituents—

Montmorillonite	...	...	...	...	$8\text{H}_2\text{O}, \text{MgO}, \text{Al}_2\text{O}_3, 5\text{SiO}_2$
Saponite	...	...	...	...	Hydrated silicate of aluminium and magnesium
Sepiolite	...	...	...	...	$2\text{H}_2\text{O}, 2\text{MgO}, 3\text{SiO}_2$
Talc	...	...	...	...	$\text{H}_3\text{O}, 3\text{MgO}, 4\text{SiO}_2$
Vanadium silicate	...	...	...	...	Composition doubtful

These constituents can be divided into two main groups as regards their physical properties, viz., crystalloids, of which the principal are kaolinite, quartz and mica; and hydrogels of which the principal are halloysite, limonite and humus. The former group form the rigid skeleton of a raw ceramic body, the latter, with water, the lubricant and adhesives which enable the wetted clay to be modelled and subsequently to retain its shape.

Major Constituents.

Kaolinite.—Hydrous silicate of aluminium, $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$. This is a pure white crystalline substance, occurring in all clays in minute scales, most of which are less than one-tenth millimetre in diameter and may be of colloidal size. The scales are soft and pliable. On burning, kaolinite yields pure white bodies at all temperatures, but becoming denser and harder at higher ones. Complete fusion only occurs at $1,820^\circ\text{C}$., so that this mineral is the most refractory of all the important constituents of clays. It forms by far the greater part of most “washed kaolins” or “true china clays” and is plentiful in all commercial clays, the utilisation of which depends to a large extent upon the properties of kaolinite.

The chemical changes taking place during the heating of kaolinite are briefly*—

Up to 100°—Evaporation of adherent moisture.

450-650—Complete removal of combined water (endothermic reaction).

(650-750°) (Sato) (1000° (Mellor)—Dissociation into alumina and silica (strongly endothermic).

1200-1300°—Recombination of alumina with part of the silica to form fibrous crystals of mullite, $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, the balance of the silica appearing as a cristobalite (SiO_2)†.

Kaolinite is very resistant to boiling strong hydrochloric acid, but is decomposed completely by hot fuming sulphuric acid.

Halloysite.—Hydrous silicate of aluminium, $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}_2\text{O}$. The proportion of water varies under different conditions.

Air dried	...	...	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}_2\text{O}$	...	4 Mols.
Dried over sulphuric acid			$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O} + \text{H}_2\text{O}$	...	3 Mols.
Steam dried	...	...	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	...	2 Mols.

This is one of the commonest and most important constituents of clays. It is a pure white or very pale green mineral of the consistency of wax. It is a typical hydrogel, non-crystalline, and readily swelling and dispersing in water into a colloidal suspension. It is the chief, and often the sole, colloid in clays, being identical with Mellor's "clayite" (a term unknown to mineralogy). With certain proportions of water it forms a thin slime or cream of high lubricating properties. It is the presence of this slime between the crystalline particles of wetted clays that gives them their essential property of plasticity, and it is the drying of this slime in intimate contact with the other constituents which binds them together into a strong mass which can be handled without crumbling.

Halloysite, on heating, behaves in a very similar manner to kaolinite, except that on drying at 100°C. it gives up more water and acts as a binding agent to the other constituents of the clay. It ultimately (above 1000°C.) becomes, like kaolinite, a mixture of mullite and tridymite or cristobalite. It gives white bodies at all temperatures.

Damp halloysite shrinks enormously during air and steam drying, and again on firing, and it is to the presence of much halloysite that ball clays and other plastic clays owe their excessive shrinkage. Unlike kaolinite it is completely decomposed by boiling strong hydrochloric acid.

No satisfactory method for the determination of the actual percentage of halloysite in a clay has ever been worked out. It appears probable, however, that an approximate calculation might be made from either the molecular

* S. Sato *Jour. Chem. Ind. Japan*, 1918, XXI., 631.

† Hyslop & Rooksby (*Trans. Cer. Soc.* XXVII., 96) give a somewhat different scheme of alterations, viz.:

Up to 550° Kaolin stable.

550 - 870° Alpha crystals stable ($? \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$).

870 - 990° Alpha disappearing, mullite and beta crystals forming ($? \text{Al}_2\text{O}_3 \cdot 10\text{SiO}_2$).

990 - 1060° Beta and mullite stable.

1060° Beta disappearing, mullite and cristobalite stable.

ratio of alumina to water, or from the solubility in strong hydrochloric acid or from the absorption of malachite green or other suitable dyes. From the figures obtained in the Government Laboratory it appears that one gram of halloysite will absorb about 0.4 grammes of malachite green, from which the percentage of halloysite equals the Ashley figure divided by 8, when halloysite is the colloid present.

Quartz.—Silica, SiO_2 . Quartz in angular or rounded grains, varying in size from several millimetres to a small fraction of a millimetre, is a constituent of all clays to a very variable extent. Natural mixtures of kaolinite and halloysite with quartz are found with quartz in all proportions from 1 to 99 per cent. The coarser grains constitute almost the whole of the natural "grit" of clays.

Pure quartz is colourless or milk white and retains its white colour when burnt. It melts at about 1700°C .; no exact temperature, however, can be fixed, as quartz over a range of about 100°C . passes through all stages of deformability lying between isotropic solid rigidity and viscous fluidity, besides which, if the rise in temperature be slow, molecular readjustments take place.

No chemical changes occur in the heating of quartz, but three molecular rearrangements take place as follow:—*

Up to 575°C .—Alpha-quartz with density 2.65.

At 575°C .—Change to beta quartz with density 2.63. Small expansion in volume (0.7%).

At 870°C .—Change to tridymite (Beta-2) with density 2.323. Expansion 13.2 per cent. by volume.

At 1470°C .—Change to cristobalite (Beta) with density 2.21. Further expansion of 5 per cent.

Total expansion from alpha-quartz to beta cristobalite is 20 per cent. of the original volume.

Because of its expansion, quartz is of great value in a clay as a corrective of the shrinkage of kaolinite and halloysite, and is purposely added with this object to many ceramic mixtures.

Though chemically stable by itself, on heating in association with other constituents of clays, many chemical reactions take place, especially with salt, iron compounds and calcite.

The proportions of quartz present in a clay, and the coarseness of the individual grains, are prime factors in determining the applicability of individual clays to industrial purposes. In fine ware, only grains less than 0.1 millimetre are permissible, coarser grains having to be screened out or ground down to this limiting size. On the other hand, particles as large as 5 to 10 mm. in diameter are often admissible in coarse refractories.

Muscovite.—Potash mica. Hydrous silicate of potassium and aluminium, $2\text{H}_2\text{O} \cdot \text{K}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$. Minute scales of this crystalline mineral are always present in appreciable quantities in clays. These are often primary constituents of the clays, derived from the rocks whose disintegration has provided the material for the clay deposit. At other times they are

* See J. W. Mellor, "Treatise on Inorganic and Theoretical Chemistry," Vol. VI, p. 242.

secondary, generated in the clay bed during the passage of geological time, by interaction of halloysite or kaolinite with potash compounds in solution in the ground water. The chief difference between the soft slates, sometimes used in brickmaking, and a recent shale or bedded clay, is that in the former, all or almost all of the original halloysite and kaolinite has been converted mainly into muscovite, but partly also into chlorite. Most of the so-called felspar of clays is really a mass of microscopic scales of mica, keeping the external form of a felspar from which they have been derived.

The muscovite of clays is usually almost pure white, but may be slightly tinted by iron. On burning, a white or almost white body results.

Important chemical changes take place in heating muscovite. At 350°C. one quarter of the water is lost and at 800°C. the remainder evaporates. Somewhere below 1180°C., the mineral breaks up into a mixture of tridymite and orthoclase (felspar).^{*} At about 1200°C. the orthoclase melts and binds the whole mass into a steel hard impervious porcelain. This mixture only flows as a whole at about 1400°C.

The practical and industrially important effect of an appreciable amount of mica in a clay is to bind it during burning, and render it steel hard and more or less impervious at the comparatively low temperature of 1200°C. It is therefore to be looked upon as one of the most useful and universal fluxes for the more refractory constituents of a clay.

Limonite.—Hydrated oxide of iron, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}^\dagger$ is the chief colouring agent of yellow, pink, brown and red clays. It is probably part crystalline, in part non-crystalline, often possessing the properties of a hydrogel, and giving under suitable circumstances (e.g., in the presence of protective and dispersive colloids) colloidal suspensions and slimes which add to the plasticity of the clay in which they occur and help to bind them when drying. At other times limonite forms hard gritty grains or pebbles in clays.

Limonite is of practical importance in two different ways. Firstly it is the chief colouring agent of clays and clay products. Burnt by itself it loses its water at a low temperature and burns to various shades of red, losing oxygen and passing into magnetic oxide, Fe_3O_4 , between 1200° and 1350°, and melting ultimately at about 1500°C. Burnt in conjunction with other clay constituents it gives compounds with various shades of yellow, pink, red, brown, grey and black.

Secondly, it is a powerful flux, yielding compounds with other clay constituents, especially quartz and alkalies which are freely fluid at temperatures of 980°C. upwards. Thus $\text{NaFe}'''\text{Si}_2\text{O}_6$ melts at 980°C.; $\text{Fe}''_2\text{SiO}_4$ at 1100° and $\text{CaFe}''\text{Si}_2\text{O}_6$ at 1140°C. These fluid compounds bind the whole mass together into a hard impervious mass, a considerable shrinkage accompanying the process. Local concentrations of such easily fusible combinations are the cause of the unsightly black or dark brown spots in bricks of various types, and of the small dark specks seen in white and cream coloured ware.

^{*} Some authorities say they change into leucite and sillimanite. Leucite has the formula $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, with a melting point variously determined at 1305° to 1430°C.

[†] Recent work has indicated the chemical identity in composition of limonite with goethite, both having the formula given above.

Minor Constituents.

Salt.—Chloride of sodium, NaCl. In countries possessing a high average rainfall and good drainage, the percentage of salt in any local clay would be quite inappreciable. For this reason we find practically no reference to its presence in, or effects on, ceramic materials in any of the recognised authorities.

In extra tropical Western Australia on the other hand, there is a very large area, with a rainfall of 15 inches or less per annum and with such slight gradient towards the sea as to be devoid of well defined drainage channels. Furthermore much of it has within recent geological times (Miocene period) been under the ocean, during which time the weathered zone was thoroughly impregnated with common salt and other oceanic salts. The result of this is that whilst most of the clays which occur close to the western coast, where the rainfall is high, and the drainage usually good, are as free from salt as most British and foreign commercial clays, those which occur beyond this limited region contain sufficient salt to seriously affect their ceramic properties. A maximum of 7.37 per cent. of water-soluble salts, of which 5.95 per cent. was common salt, was found in a white clay from Kanowna. This, however, is quite exceptional, the usual amount found being less than one per cent.

Salt, even in quite small quantities, however, exerts an extremely deleterious effect upon clay. In the raw state it reduces the plasticity by coagulating the colloids. On drying a modelled article, the salts concentrate at the surface and in quantities of 2 per cent. or more, fret the surface during crystallisation. Again, salt is by far the most powerful of all fluxes found in clay, quantities as small as 0.5 per cent. reducing the vitrifying point by 100 or more degrees. The fluxing effect is due to its melting at 800°C. and thereafter combining with the free quartz and silicates of the clay to form one or more of the following readily fusible compounds, with simultaneous evolution of chlorine gas.

$\text{Na}_2\text{Si}_2\text{O}_5$	...	...	...	...	...	Melting point	874°C.
$\text{NaFe}^{++}\text{Si}_2\text{O}_6$	...	...	...	...	...	"	980°C.
Na_2SiO_3	...	...	...	...	...	"	1090°C.*
NaAlSiO_4	...	...	...	...	...	"	1170°C.
$\text{NaAlSi}_3\text{O}_8$	...	...	...	...	...	"	1220°C.

Since during drying the salt becomes very unequally distributed through the body, the fusibility is similarly uneven, being greatest at the surface and at sharp edges, where evaporation deposits it from solution. This low fusibility of the surface, combined with the evolution of chlorine at the fusion point, is responsible for serious blistering whenever the proportion of salt in the clay rises above 0.5 per cent. Abundant instances of this effect have been met with during the course of this research and illustrations of typical cases are to be seen in the accompanying figures.

A further evil effect of salt is the transference of iron during burning from iron bearing material such as the walls of the kiln or ferruginous clay articles, to articles devoid of iron, which would otherwise burn white. This effect is due to the chlorine from the salt converting ferric oxide into volatile ferric chloride which circulates round the kiln and forms dark coloured ferric silicates on surfaces of suitable temperature and composition.

* Eutectic of Na_2SiO_3 with CaSiO_3 , 1060°. (Morey & Bowen Trans. Soc. Glass Tec. IX. (1925) 247).

All things considered, common salt is by far the most deleterious constituent ever found in clays and one which needs removal by weathering or washing, whenever it exceeds 0.3 per cent. in amount. In testing local clays its determination is the first test to be applied, and if present in more than this amount a thorough washing always precedes the burning tests.

The known beneficial effects of weathering a clay are partly attributable to the complete removal of salt and other water soluble compounds which prevent dispersion of the colloids, and so lower the plasticity of the clay.

The removal of salt on a commercial scale would be effected by weathering in the open, or by filter pressing a suspension of the clay in water.

Calcite.—Carbonate of calcium, CaCO_3 . This is an appreciable and often prominent constituent of many English and foreign clays, but appears to be totally absent or almost so, from all the Western Australian clays so far examined. Concretions of calcite have, however, been encountered in some abundance in a terra cotta clay at Belmont.

Calcite breaks up at a red heat into lime and carbonic acid gas. The lime thus formed is highly infusible by itself, but in contact with quartz and various silicates forms compounds with comparatively low melting points, for example $\text{CaFeSi}_2\text{O}_6$ and $\text{CaNa}_2\text{Si}_2\text{O}_6$ both melt at 1140°C ., $\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ at 1200°C ., $\text{CaMgSi}_2\text{O}_6$ at 1310°C ., $\text{CaAl}_2\text{Si}_2\text{O}_8$ at 1320°C . and CaSiO_3 at 1340°C . *The effect of calcite in a clay is therefore that of a flux, reducing the softening and flowing temperatures, and hardening the bodies and making them denser.

Felspar.—(Orthoclase or Microcline): Silicate of potassium and aluminium, $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$. Some soda invariably displaces part of the potassium. This is usually considered to be a frequent and important constituent of residual clays, and in calculating the mineral constitution of ore from its chemical analysis, the whole of the potash (and soda) is often calculated as orthoclase. This is quite justified in dealing with "Cornish stone," a partly kaolinised granite, whose equivalent has not yet been worked in Western Australia. But in the examination of the many clays dealt with in this address, and including many residual clays, undoubted felspar was only observed in one or two instances. Nothing at all like felspar could be detected in the majority of them, and material resembling felspar at first sight, when separated from others, was found in every case to be mica pseudomorphous after felspar. The alkali bearing mineral in all the sedimentary clays examined and in the great majority of residual clays was muscovite mica.

Felspar is a most important flux when present in such material as "Cornish stone," or when artificially added to a clay mixture. It melts at about 1200°C . to a tough white or greyish white enamel.

Humus.—Mixture of various compounds of carbon, hydrogen, nitrogen and oxygen resulting from the recent decay of vegetable matter. This occurs in appreciable amounts in all surface clays, and clays of very recent geological age. Consisting almost wholly of colloidal matter, much of which acts as a dispersive colloid on the inorganic hydrogels of the clays, it has an appreciable effect in the direction of raising the plasticity of clays. Like coaly matter too, it increases the porosity of the burnt bodies. Though often responsible for a dark colour in the raw clay, this colour is lost on burning by

* C. Doelter, H. B. der Mineral Chemie, 1, 658; Money & Bowen (1925) and others.

the complete combustion of the humus. A clay of grey colour in the raw state must not therefore be condemned for use in making light coloured ware, but judgment should be withheld until burning tests have been made.

Coal Substance.—Mixture of various compounds of carbon, hydrogen, nitrogen and oxygen. The humus of recent clays loses with passage of geological time, certain volatile constituents, and becomes of the nature of lignite, brown or bituminous coal. Such material is found in shale beds of past geological ages and is specially plentiful in the bedded clays (shales) of the Permian and Carboniferous formations, e.g., those of the Collie district. The presence of this material increases the porosity of the burnt body, but does not necessarily stain it, as the coloured carbon compounds, under normal conditions, completely burn out of the clay mixture in the kiln.

In some countries, for certain purposes a reducing atmosphere is maintained in the kiln so as to prevent the oxidation of the carbon.

Coaly matter is of practical importance to the potter, in that it consists partly of colloidal substances, some of which act as protective and dispersive colloids, to the halloysite and kaolinite of the clays, thus adding to their plasticity. Further, in burning such clays, local heat is generated in actual contact with the clay and the final removal of the coal substance by combustion leaves the body more porous than it would otherwise be.

A clay which in the raw state is very dark coloured from the presence of coaly matter may burn to a white or almost white body. This is true of some Collie clays.

Chlorite.—Hydrous silicate of aluminium, magnesium and iron. $x(2\text{H}_2\text{O} \cdot 2\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2) + y(2\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 2\text{SiO}_2)$. This is a minutely scaly, green mineral found in small proportions in the older shales and slates (e.g., Cardup-Armadale) as well as in the completely kaolinised greenstones. It acts as a flux, and as a red, brown or black colouring agent.

Opal.—Hydrous silica, $3\text{SiO}_2 \cdot \text{H}_2\text{O}$. This occurs in traces on some residual and other clays, hardening them somewhat and making them difficult to disintegrate, besides reducing the plasticity. It loses part of its water at 100°C . and most of the remainder between that and 400°C ., thereafter acting as quartz.

Gibbsite and Cliachite.—Aluminium hydroxide, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. Both minerals have the same composition, but Gibbsite is crystalline whilst Cliachite is a hydrogel. They are of rare occurrence in true clays and in Western Australia have as yet only been detected in one from Bolgart. As, however, nearly all our residual clays are covered with a crust of laterite composed of ironstained Gibbsite and Cliachite, small fragments of these minerals are liable to find their way into commercial parcels of clay. The chief effect produced is ascribable to the iron (limonite) content which gives fused slag spots in the finished ware, particularly noticeable in our local firebricks. Pure Gibbsite and Cliachite are dehydrated at a comparatively low temperature, yielding anhydrous alumina which only melts at about 2000°C ., but in the presence of siliceous material is converted into mullite ($3\text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$) at a much lower temperature.

Constituents Rarely Present in Quantities Exceeding One Per Cent.

Pyrite, Marcasite.—Two varieties of sulphide of iron. FeS_2 . Small concretions or disseminated grains of one or other of these minerals are not uncommon in carbonaceous shales protected by a fair thickness of over-

burden, *e.g.*, some shales in the Collie coal basin and Swan Coastal Plain. They are objectionable constituents, as they are always irregularly distributed and during burning lose their sulphur and become oxidised to ferric oxide which acts as a strong local flux and pigment. They are absent from clays to which the air has a free access, and usually from those devoid of carbonaceous matter.

Rutile, Brookite and Octahedrite.—These three are different forms of titanium oxide, TiO_2 , all of which have been detected in local clays. For example, octahedrite in the heavy concentrate from clay from Kunjin; brookite in the same from Yuna, Carmel and Victoria Park; and rutile in the same from Collie, Donnybrook, etc. In all cases the total proportion present probably does not exceed one tenth of one per cent. Titanium dioxide even in small quantities is said to give a faint yellowish tint to an otherwise white body.

Doelterite.—Hydrated oxide of titanium, $\text{TiO}_2 \cdot \text{H}_2\text{O}$. This mineral usually accounts for the greater part of the titanium found in the analyses of recent surface clays. In these it may occur as a fine powder, evenly distributed and forming up to one per cent. of the whole mass. In the laterites, fragments of which are apt to contaminate the underlying residual clays, doelterite forms from one to five per cent. of the whole. From the potter's point of view, it is chiefly of importance because of its suspected tinting capacity.

Ilmenite.—Titanate of iron, FeTiO_3 . This hard crystalline mineral occurs in many sedimentary clays in the form of small heavy black grains which are readily detected during the mechanical analysis. It is never present to the extent of more than a fraction of one per cent., and in red ware or coarse ware of any kind is negligible. In white ware clays, however, it is a serious impurity, as it is one of the chief causes of the small black specks often appearing in such ware. It is a strong colouring agent and a flux, and can only be removed by electro-magnets, or electro-osmosis, or by careful levigation.

Siderite.—Carbonate of iron, FeCO_3 . Small quantities of this compound exist in some Collie shales and in others of the older bedded shales of Carboniferous, Permian and Mesozoic ages. On burning, the carbonate is oxidised to ferric oxide, which acts as a flux.

Zircon.—Silicate of zirconium, ZrSiO_4 . This heavy, hard crystalline mineral is found in small quantities in the heavy concentrates from most Western Australian clays. Its effect from a potter's point of view is negligible.

Gypsum.—Hydrous sulphate of lime, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Small quantities of this colourless and water soluble compound are found in saliferous clays and are said to be responsible for the greater part of the unsightly white scum which develops on the surface of some red bricks. As gypsum is water soluble, it can be removed if necessary from the raw clay by weathering or artificial washing. It is rarely, however, present except in quite small quantities.

Alunite.—Hydrous sulphate of potassium and aluminium. $6\text{H}_2\text{O} \cdot \text{K}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 4\text{SO}_3$. This occurs disseminated or in nodules in almost all the commercial clays raised at Kanowna. Alunite on heating to a temperature of 420°C . loses two-thirds of the water, and at 525°C . the balance. At 800°C . three quarters of the sulphuric oxide is split off, the balance being

lost at about 950°C . with the formation of potassium aluminate, or aluminosilicate if silica is present. In small proportions in a clay it has been found to act as a harmless flux.

Doubtful Constituents.

Magnesium silicates.—The analysis of practically every clay indicates the presence of quantities of magnesium ranging from traces up to one per cent. or even more. Only rarely does one find no magnesia whatever, local examples being washed kaolin from Glen Forrest, and the Bolgart, Mt. Kokeby and Elgin white sedimentary clays. In the older bedded rocks used for ceramic purposes such as the Gosnells-Cardup slate, the magnesia has been proved by microscopic examination to be present in chlorite. In the more recent calcareous sediments, such as those of Dongarra, it is probably present as a carbonate associated with calcium carbonate. In the majority of clays, however, it appears to exist as a silicate whose mineralogy has not yet been worked out. Recent work, both in Australia and abroad leads to the belief of the existence of the hydrogelatinous or colloidal magnesium silicate $\text{H}_4\text{MgSi}_3\text{O}_9 + 2\text{H}_2\text{O}$ * isomorphous with halloysite, $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9 + 2\text{H}_2\text{O}$, and occurring frequently in intimate conjunction with it in various proportions. This mixture is especially noticeable in many bentonites, and fullers earths (*e.g.*, that from Watheroo), and is the basis of such clay-like “minerals” as montmorillonite†, saponite, etc. Such minerals increase the plasticity of clays greatly and their fusibility somewhat.

Sepiolite, $2\text{H}_2\text{O} \cdot 0.2\text{MgO} \cdot 0.3\text{SiO}_2$, and tale $\text{H}_2\text{O} \cdot 0.3\text{MgO} \cdot 0.4\text{SiO}_2$ are suspected of being present in some clays.

Vanadium Silicate.—A complex silicate containing vanadium, probably vanadiferous muscovite, is present in very small quantities in many clays. It is best detected by burning a briquette of the clay between 1100° and 1200°C ., just saturating it when cold with water, and then setting aside to dry. During the burning the vanadium is converted into potassium vanadate, a water soluble salt of a brilliant yellow colour, which dissolves in the added water and is brought out on the surface during drying, remaining as a brilliant yellow stain. In the presence of abundant dust or other reducing agent the stain may be greenish yellow or green. The same stain is sometimes produced on a stack of bricks wetted for the first time by a shower of rain and then dried again by the sun. In this State it is often observed on the surface of the Glen Forrest firebricks (made from kaolinised granite and dolerite) and the Albany house bricks (made from a Miocene sediment). In the laboratory it has been observed on briquettes made from a large number of light coloured clays of all types. It was extremely strong on a white burning clay of doleritic origin from Balkuling (L. No. 9637E), and quite distinct on many others including No. 1121/25 Boyup Brook; Nos. 1329/23 and 2222/23 Quairading; No. 2016E, Jacob's Well, etc.

TEXTURE OF CLAYS.

The texture, or mechanical composition, of a clay is its constitution in terms of the sizes and forms of its individual grains, irrespective of their chemical composition. The finer types of ceramic ware can only be made

* This might conveniently be known as picrocollite.

† A mixture of equal molecules of halloysite and picrocollite has the composition $4\text{H}_2\text{O} \cdot \text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2 + 4\text{H}_2\text{O}$, which is exactly the formula deduced by Ross and Shannon for montmorillonite which they consider to be the chief constituent of bentonite (*Jour. Am. Cer. Soc.* IX, 89).

up of bodies whose individual particles will all pass a 100 to 200 mesh screen, *i.e.*, whose particles are not more than 0.05 to 0.15 millimetre (0.002 to 0.006 inches) in diameter, whilst the coarsest ware, such as bricks, can be made of clay with certain proportions of particles one hundred times as large as this. In consequence the texture of a clay has a marked bearing upon its possible application, more particularly as only a limited amount of grinding, sifting or elutriation is economically permissible.

In the Western Australian Laboratory it has been customary to determine the grain size by levigation of the finest particles and sifting of the coarser. Each clay is thus divided up into five fractions, *viz.*:—

1. Clay substance.
2. Grit under 90 mesh (0.18 mm.).
3. Grit under 60 mesh (0.26 mm.).
4. Grit under 30 mesh (0.60 mm.).
5. Grit over 30 mesh.

The methods by which these are determined are given in a subsequent chapter (p. 206). The clay substance is the finest grained material capable of remaining in suspension in water for several minutes.

As examples of the wide ranges in texture found amongst local clays the following may be taken:—

China clay prepared on a large scale in the laboratory by levigation of Glen Forrest kaolinised granite was composed entirely of particles under 200 mesh (0.05 mm.), *i.e.*, "clay substance." Analysis showed that this clay substance comprised 91 per cent. kaolin and halloysite, 5 per cent. mica, 3 per cent. quartz and 1 per cent. moisture.

The completely kaolinised granite from which this china clay was prepared had the texture shown in "B." This is used in making firebricks and lumps.

The associated kaolinised dolerite (epidiorite) mixed with "B" for making refractories, had the texture shown under "C."

Mark	...	...	A.	B.	C.	D.	E.	F.	G.
Clay	...	...	China clay.	Kaolinised granite.	Kaolinised dolerite.	Sedimentary fireclay.	Semi-ball.	Ball.	Fuller's Earth.
Locality	...	...	Glen Forrest.			Collie.	Mt. Kokeby.	Kalamunda.	Collie.
Clay substance	...	...	100	59	97	66	91	95	99
Grit —90	...	...	...	1	1	25	9	2	1
Grit —60	...	...	...	3	1	9	Trace	2	Trace
Grit —30	...	...	...	6	1	Trace	Trace	1	Trace
Grit +30	...	...	...	31	Trace	Trace	Trace	Trace	Trace

A sedimentary fireclay from Collie with a high proportion of fine grit (quartz) is shown under "D."

A white sedimentary semiball clay from Mt. Kokeby is given under "E" and a ball clay from Kalamunda under "F." Both of these are levigated and screened during the manufacture of white semiporecelain.

A Collie fuller's earth of extremely fine grain is shown under "G."

As regards the shape of the particles, this is usually noted in regard to the grit fractions. If these consist largely of fine scales of mica, a much smoother finish is obtained on such an article as a roofing tile than if they consist mainly of angular quartz grains.

SUBSIDIARY CERAMIC MATERIALS IN WESTERN AUSTRALIA.

Several mineral substances are used by potters to modify the properties of natural clays as exhibited both in the raw working and burning. Those in commonest use are china clay, "Cornish stone," flint (quartz) and felspar. Of more restricted use are bone-ash, beryl and various minerals, required in the manufacture of refractory bricks and blocks.

China Clay.—The world famous "china clay" of Cornwall, known also as "washed kaolin" is almost pure kaolinite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) mixed with some equally valuable halloysite ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O} + 2\text{H}_2\text{O}$), and obtained by sluicing and levigating completely kaolinised granitic rocks. It is added to crude clays, or used in place of them, not because of its plasticity which is of a low order, but because of its softness and extremely fine grain, and its pure whiteness after burning. The addition of it to a ceramic mixture improves the smooth working of the clay, gives a fine finish to the ware and finally ensures the whiteness of it. The Cornish mineral is largely used in England, Europe and America, and is regarded as the standard of what a washed kaolin or high grade kaolinite should be.

There is no reason why South-Western Australia should not become the Cornwall of Australia. The knowledge of our clay resources acquired during the last twenty years establishes the fact that in this part of the Commonwealth there is a very large area (about 20,000 square miles) of granite seamed with dykes of dolerite, or derived epidiorite, and partly overlain by a thin layer of laterite or sand. This granite and its accompanying greenstones are in many localities, some of them close to Perth, completely altered, for 20 feet or more below the overburden, into soft white clayey masses, from which all the iron has been leached and drawn to the surface to form laterite. In the case of the greenstones, the rock in mass consists of 80 to 93 per cent. kaolinite and halloysite, the balance being finely divided quartz and mica. Such a rock on washing will yield 85 to 95 per cent. of high grade china clay. In the case of the granites, a large proportion of coarse quartz granules is always present, the content in kaolinite plus halloysite being 45 to 60 per cent. The yield of excellent china clay from such a rock will be from 50 to 65 per cent. whilst the residual quartz is suited for use as a "flint." The washed kaolin from either class of rock will run freely through a 200 mesh screen, and burns to a good white colour somewhat purer as a rule in the case of the granitic clays than the dolerite clays, which contain larger amounts of titanium and vanadium.

Some figures regarding actual samples of raw material are worth quoting:—

No.	Rock.	Texture.				
		Clay Sub-stance.	Grit —90.	Grit —60.	Grit —30.	Grit +30.
1900/18	Kaolinised granite, Glen Forrest	65·3	4·3	2·2	3·9	24·3
1550/17	Kaolinised granite, Kalamunda	74·8	9·1	5·6	4·7	5·8
1766/18	Kaolinised granite, Kondut	54·8	2·5	4·2	10·2	28·3
1427/28	Kaolinised granite, Pingelly	58·2	4·8	3·8	6·6	26·6
2112/19	Kaolinised granite, Ten-terden	52·0	1·1	3·7	11·5	31·7
3514/19	Kaolinised dolerite, Glen Forrest	96·9	1·2	1·1	0·5	0·3
4158/20	Kaolinised dolerite, Kalamunda	89·7	7·4	1·4	0·8	0·7
3819/20	Kaolinised dolerite, Cardup	93·3	2·3	1·9	1·9	0·6
4222/20	Kaolinised dolerite, Kunjin	95·2	4·0	0·4	0·3	0·1

The figures for "clay substance" give the approximate yield of washed China Clay.

Analyses:

The following analytical figures are typical:—

—	1900B. Washed kaolin from granitic clay Glen Forrest.	3514. Kaolinised dolerite, Glen Forrest.	3819. Kaolinised dolerite, Cardup.	4222. Kaolinised dolerite, Kunjin.
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Ultimate Composition.

SiO ₂	45·57	52·19	51·25	46·51
Al ₂ O ₃	37·93	34·18	34·19	38·12
Fe ₂ O ₃	·31	·64	·64	·40
MgO	Nil	Nil	Nil	Nil
MnO	Nil	Nil	Nil	Nil
CaO	Nil	Nil	Nil	·09
Na ₂ O	·11	·10	·16	·12
K ₂ O	·58	·51	Traces	·32
H ₂ O —	1·07	·50	1·23	·50
H ₂ O +	12·36	11·38	12·26	13·68
TiO ₂	·22	·34	·45	·62
NaCl	Slight trace	·15	·15	·16
SO ₃	Nil	Trace	Trace	·05
Other soluble salts ...	Nil	·02	·03	Trace
	100·15	100·01	100·36	100·57

Approximate Mineral Composition.

Kaolin	90·4	80·7	84·8	93·2
Mica	5·3	5·5	2·0	4·0
Quartz	2·8	11·8	10·9	1·5
Limonite	·4	·8	·8	·5
Salt	Slight trace	·1	·1	·2
Minor constituents ...	1·1	·5	·6	·5
Moisture	·2	·6	1·2	·7
	100·2	100·0	100·4	100·6

The area from which a production of china clay may be effected in the future is that part of the Darling Range immediately east of Perth and thence southwards. This is an area with a high rainfall, and consequent good water supply, whilst raw material for washing is abundant and easy of access.

South-Western Australia possesses a number of pure white sedimentary clays of very fine grain which are practically natural china clays.

Cornish Stone.—This partly kaolinised granite or pegmatite, found associated with china clay deposits in the West of England, is in high repute as a flux. Its fluxing properties are due to the high proportion of felspar and mica present in it, the usual content in potash being between 6 and 7 per cent.

So far no typical Cornish stone has been discovered in Western Australia, but there is little doubt that if some of the granitic clay pits were deepened or their floors bored, supplies of this valuable flux would be disclosed. In the meantime some of the highly micaceous white clays known on the Coolgardie Goldfields should be worthy of a trial as a substitute.

Felspar.—In default of Cornish stone, almost pure hand picked felspar is used in large quantities as a flux in Europe, America and Japan. There are two distinct felspars in use, viz., Microcline (potash felspar) and Albite (soda felspar). All microclines carry a little soda and many albites a little potash. Finegrained intergrowths of the two minerals are not uncommon and are known scientifically as "Perthite." Felspars do not melt sharply as the temperature rises, but soften over a range of about 50°C. and become fluid between 1140°C. and 1220°C. The presence of soda and potash felspar is said to raise appreciably the melting point, and the viscosity of the fused mineral. After fusion the mineral has an increased volume of 7 per cent.

Both felspars are found in commercial quantities in pegmatite veins, which in South-Western Australia are abundant in the granite masses, *e.g.*, at Mahogany Creek, Mooliabeenie and Jacob's Hill, or stretching out from them into the surrounding greenstones, as for example at Balingup, Londonderry and Ubini. Further afield there are immense quantities of high grade felspar, both microcline and albite, available at Wodgina, Tabba and other tin and tantalum fields in the north-west of the State. Many pegmatite veins are far too narrow to be worth working, others are unworkable because of the small percentage of felspar, or its small size, rendering hand picking too laborious and costly. In some places the felspars are too ferruginous to be used for white ware, a maximum content of 0.2 per cent. Fe_2O_3 being all that is permissible without running the risk of producing badly tinted ware. In Western Australia, however, many of our felspars are of excellent white or pale grey colour and unusually free from iron.

Tentative specifications for felspar for ceramic uses drawn up by Professor A. S. Watts in the United States in 1920* included the following provisions:—

Potash felspar shall contain at least 9% K_2O , not more than 3% Na_2O and 1% CaO . The sum $\text{K}_2\text{O} + \text{Na}_2\text{O}$ to be at least 12%. Soda felspar shall contain at least 7% Na_2O , and not more than 3% K_2O and 2% $\text{CaO} + \text{MgO}$. The sum $\text{Na}_2\text{O} + \text{K}_2\text{O}$ to be at least 10%. Mixed or blended felspar shall contain at least 11% $\text{K}_2\text{O} + \text{Na}_2\text{O}$.

* *Jour. Am. Cer. Soc.* 1920 p. 722.

No standard for iron content is laid down, though this is of the highest importance to white ware makers.

These specifications were reviewed by a committee who reported in 1923.* This committee recognised four grades of felspar as follows:—

Grade.				K ₂ O	Na ₂ O	CaO.MgO	
A	...	...	...	Over 10	Under 3·6	Under 0·75	} Potash felspar.
B	...	...	...	Over 9	Under 3·2	Under 1·00	
C	...	...	...	Over 7·8	Under 2·8	Under 1·00	
D	...	...	...	Under 3·0	Over 7·0	Under 1·00	Soda felspar.

Still no standard for iron was suggested.

Later in 1923†, J. Turner discussed requirements for this material and suggested a lower permissible total for alkalis, viz., 10%. Regarding colouring agents he said, "The analysis should give no more than a trace of iron or other darkening minerals, and when fused should be free from specks to anyone with good eyesight (not using a magnifying glass). The fused felspar should be white drifting towards the warmer cream suffusions rather than a cold bluish white."

It appears from these and other statements, that a pottery felspar is still considered to be of first class quality if it is associated with not more than 10 per cent. of white quartz, is free from coarse flakes of muscovite, and included grains of black minerals (biotite, iron ores, etc.), as well as from brown iron staining, the total iron content not rising above 0.2 per cent. of Fe₂O₃.

Analyses have been made of a number of Western Australian felspars suitable for pottery purposes and obtainable in commercial quantities. In comparing these with any specifications for felspar it is to be remembered that the local analyses were made on the pure mineral, whilst truck lots would invariably contain some associated quartz and probably small quantities of mica, etc.

WESTERN AUSTRALIAN FELSPARS.

Microcline.

Locality.	Mahogany Creek.	Payne's Find.	Londonderry.		Jacob's Well.	Balingup.	Pingelly.
			Foch Mine.	Haig Mine.			
K ₂ O	12·20	14·96	11·44	13·24	10·31	12·37	13·53
Na ₂ O	3·08	1·51	3·18	2·32	4·33	2·85	2·44
CaO	Nil	Nil	...	Nil	...	...	...
Fe ₂ O ₃	·10	·07	·07	·07	·13	·09	·12
Al ₂ O ₃	19·11	18·78	...	18·51	...	...	...
SiO ₂	65·46	64·40	...	65·00	...	...	...

* Bull. Am. Cer. Soc. 1923, p. 163.

† Bull. Am. Cer. Soc. 1923, p. 367.

Albite.

Locality.	Jacob's Well.	Wodgina.	Ravensthorpe.	Ubini.
K ₂ O	·66	·18	·04	·14
Na ₂ O	10·77	11·06	10·83	10·98
CaO	·24	·22	Nil	·41
Fe ₂ O ₃	·11	·03	Trace	·06
Al ₂ O ₃	19·94	19·67	19·44	20·59
SiO ₂	68·19	67·87	69·13	67·87

The analytical figures for the local microclines should be compared with the following published figures for foreign feldspars largely used in the pottery industry.

Locality.	Rorstrand, Sweden.	Noresto, Norway.	Middleton, Connecticut, U.S.A.	Hybla, Ontario, Canada.
K ₂ O	11·83	11·11	11·89	10·00
Na ₂ O	2·96	3·67	2·98	3·48
CaO	·02	Trace	·04	·52
Fe ₂ O ₃	·16	·08	·30	·22
Al ₂ O ₃	18·53	20·22	18·63	18·01
SiO ₂	65·56	64·70	65·18	66·82

The feldspars used hitherto in the Perth potteries have been microcline from Londonderry and albite from Ubini. Other deposits with good commercial possibilities are those of microcline and albite at Jacob's Well and Toodyay, microcline at Balingup and Mooliabeenie and albite at Ravensthorpe. There are a number of other localities known, particularly on the Pilbara tinfields, but they are less accessible to the potteries. At all the places mentioned the feldspars are characterised by their exceptionally white colour, and concomitant freedom from iron oxide.

Flint.—Some variety of natural silica forms an invariable constituent of all pottery, as without it the shrinkage of the moulded ware would be excessive during both air drying and burning. In the case of the rougher wares, clays are chosen which already contain the necessary proportion of quartz. In the case of finer ware, with a base of washed kaolin and finely ground felspar or Cornish stone, it is necessary to add silica in the form of ground flint or quartz. In England and Western Europe, where flint is abundant and remarkably free from iron, this is the material almost solely used. In Western Australia flint is rare and not known in commercial quantities, but vein quartz and quartz sand of a high degree of purity are both very common.

Up till now quartz sand has been used in the local potteries, one source of supply being the extremely white and pure sand from Lake Gnangara, 10 miles north of Perth. Other suitable sands are known at Bassendean, Maddington, Gingin, Busselton and Albany, and doubtless there are many other equally valuable deposits not yet prospected, as surface sands of varying quality are prominent features of much of the coastal area of the South-West. The best are often closely associated with swamps carrying peaty water, which has been responsible for dissolving out, or preventing the precipitation, of ferrous carbonate or ferric hydroxide, which contaminate the larger proportion of the local sands.

The following figures are typical of these sands:—

Locality.	Gnangara.		Bassendean.		Maddington.	Gingin.	Albany.
Ignition Loss After Ignition—	·07	·84	·57	·03	·12	·10	·20
SiO ₂ ...	99·64	99·65	99·80	99·83	99·80	99·91	99·00
Fe ₂ O ₃ ...	·028	·034	·022	·007	·032	·014	·07
Grain Size—							
Over 1 mm.	Nil	Trace	·1	Trace	·2	Nil	Nil
„ .75 mm.	·1	5·6	10·0	5·5	9·4	·2	Nil
„ .50 mm.	·1	17·0	48·0	38·8	38·8	9·3	Nil
„ .25 mm.	89·0	69·2	38·0	53·3	42·1	87·8	27·4
„ .10 mm.	9·8	6·6	2·7	1·9	6·5	2·6	70·6
Under .10 mm.	1·0	1·6	1·2	·5	3·0	·1	2·0

The granular quartz washed on a small scale from the kaolinised granites of the Darling Range is of excellent quality for pottery purposes, and would be available in considerable quantities were the China Clay industry ever established here. A typical sample was found to carry only 0.08 per cent. Fe₂O₃ with about 99 per cent. SiO₂, the grain size being: Over 1 mm., 0.4; over 0.5 mm., 14.6; over 0.25 mm., 40.1; over 0.1 mm., 34.2; under 0.1 mm., 10.7 per cent.

Vein quartz low in iron and easily quarried is available on the lower slopes of the Darling Range at Gosnells. In many other parts of the South-West and Eastern Goldfields are quartz veins of suitable purity for use in ceramics.

At Kalgoorlie, Kanowna and one or two other localities are deposits of highly siliceous, fine grained, and pure white clays, which show no shrinkage on burning, and are eminently suited for use in white ware and other potteries as a substitute for flint.

No silica bricks have yet been made in the State, and so far the raw material of suitable quality has only been located at great distances from any manufacturing centre. Bedded quartzites from the Billeranga Hills near Morawa (270 miles by rail north of Perth) and the Eyre Range on the south coast are considered suitable for this purpose. Their compositions are:—

	Billeranga Hills.		Eyre Range.
SiO ₂	99·22	99·63
Al ₂ O ₃	·32	·16
Fe ₂ O ₃	·12	·11
FeO	Nil	Nil
MnO	Nil	Nil
MgO	·03	Nil
CaO	·01	·01
Na ₂ O	·22	·04
K ₂ O	Nil	Nil
H ₂ O —	·01	Nil
H ₂ O +	·08	·06
TiO ₂	·01	·05
		100·02	100·06

Magnesite.—This valuable material for the manufacture of refractory bricks, etc., has been found in a number of places in the State, and in four localities exists as workable deposits, viz., Bulong, Coolgardie, Waverley and Ravensthorpe. Of these the first-named is by far the most important. In each case the deposit consists of veins and nodules of white porcelain-like mineral in the weathered surface zones of serpentine rock masses. Other similar but unproved deposits occur at Eulaminna and Comet Vale.

By far the most extensive deposit known is that at Bulong. From an area two miles long by a quarter of a mile wide, and within a few feet of the surface, many thousands of tons are exposed. The veins range from a few inches to two feet in width, and in many of the excavations form quite 50 per cent. of the exposed face. The associated rock is comparatively soft serpentine which is readily separated. The magnesite is pure white in colour and carries 93 to 98 per cent. MgCO_3 , with a maximum of about 2 per cent. CaCO_3 and rarely as much as 5 per cent. silica.

There are several commercial deposits close to Coolgardie under a cover of a few feet of soil. These appear to be capable of yielding a high tonnage carrying 97 to 99 per cent. MgCO_3 , nil to 1 per cent. CaCO_3 , under 0.1 per cent. Fe_2O_3 and under 1.0 per cent. SiO_2 . The deposit at Waverley is similar, but more inaccessible. An analysis of the mineral showed 98 per cent. MgCO_3 .

A few miles south-east of Ravensthorpe, surface boulders of white magnesite, derived from numerous shallow veins, are plentiful, and have been used both as a flux and in the manufacture of magnesite bricks for the local copper smelter. This magnesite averages 96.6 per cent. MgCO_3 and 2.5 per cent. CaCO_3 .

Boulders of magnesite are plentiful over a long strip of the eastern Wheat Belt in the vicinity of Kulin and Bruce Rock. This is much nearer to Perth than any of the above-mentioned deposits, and, when the finest veins are opened up, may prove to be of importance. A typical sample from Corrigin had MgCO_3 , 98.1 per cent.; CaCO_3 , trace; $\text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3$, 1.00; SiO_2 , 0.6. Another sample from Nungarin, where it is said to be plentiful, had MgCO_3 , 96.3 per cent.; CaCO_3 , 1.8; $\text{Fe}_2\text{O}_3 \cdot \text{Al}_2\text{O}_3$, 0.2; SiO_2 , 0.6.

Magnesite brick is stated to soften at $1500\text{--}1700^\circ$ and to melt at $1980\text{--}2100^\circ$.

Dolomite.—This useful refractory material has only been found in small quantities in the South-West, mainly in the Eyre Range, but among the Palaeozoic and older sediments of the North-West there are thick beds of dolomite rock, often transmuted into dolomitic marble. This is particularly the case in the Ashburton and Gascoyne watersheds, a region at present not within reach of manufacturers in industrial centres.

Typical examples are:—

Dolomitic Rocks.

				Coorara (Mt. Edith).	Irregully Creek.	Wiluna (Bubble Well)
SiO_2	...	...	...	.23	3.14	6.99
Al_2O_3	...	...	...	.20	.02	1.88
Fe_2O_3	...	...	...	Trace	.33	.65
FeO}	...	...	...	.15	.39	.52
MnO}	...	...	...	.30	.68	.87
MgO}	...	...	...	21.25	20.70	19.67
CaO}	...	...	...	30.43	29.53	26.84
Na_2O}	...	...	...	Nil	.05	.08
K_2O}	...	...	...	Nil	.12	.52
H_2O}	...	...	...	.10	.22	.63
TiO_2	...	...	...	?	Nil	.04
SO_3	...	...	...	Nil	.13	.10
CO_2	...	...	...	47.44	44.89	41.80
P_2O_5	...	...	...	.10	.11	.05
FeS_2	...	...	...	Nil	Nil	Nil
				100.20	100.32	100.64

Dolomitic marls have been observed in the South-Western Division at Rockingham, Toojelup (near Woodanilling) and Country Peak.

Chromite and Chrome Spinel.—The former, often known as chrome iron ore or chromite, consists essentially of $\text{FeO} \cdot \text{Cr}_2\text{O}_3$. In the latter, much of the iron is displaced by magnesium, and the chromium by aluminium.

These useful refractories are like magnesite, associated with serpentine rocks. Although such rocks are very widespread in Western Australia, only two deposits of chromite and spinel of workable dimensions have been reported. One lies a little east of Namban, a railway station 126 miles north of Perth; the other at Jimblebah near Murramunda at the far eastern end of the Ophthalmia Ranges. The composition of typical hand picked parcels from these two localities are:—

	Cr_2O_3	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	SiO_2	H_2O	Total
Jimblebah ...	46.16	10.89	2.78	20.48	.26	11.04	5.76	2.21	99.58
Namban ...	22.76	42.09	3.80	17.45	.26	13.65	Nil	Nil	100.01

Scientifically the Jimblebah mineral would be classified as Beresovskite*, the Namban one as Ceylonite. Both are highly refractory, the softening point under load, and fusion point being recently given as 1510° and 2050° for chromite brick with 44% Cr_2O_3 ; and 2000° and 2130° for spinel brick.

Bauxite.—This rock consists essentially of one or more aluminium hydroxides, usually contaminated with iron hydroxide. Rather low-grade bauxite is abundant as a ridge-capping, one to six feet thick, over many parts of the Darling Range. The relative proportion of aluminium hydroxide and iron hydroxide varies greatly in these beds from point to point. It is only those portions which are high in alumina and low in iron that are of value to the ceramic industry. The Darling Range bauxite is a moderately tough rock, looking like an iron-stained conglomerate; the "pebbles," however, are nearly all concretions of limonite. These nodules are embedded in a fine-grained bauxite matrix varying in colour from red to pale yellow. The lighter coloured rock is usually the richer in alumina.

So far the Darling Range bauxite has only been used as a road ballast, but as several railways traverse the range, making the deposits very accessible, there is every reason to believe that in future they will be used for higher purposes.

The most important localities are Toodyay with Al_2O_3 , 37 to 48 per cent.; Wooroloo, 38 to 48 per cent.; Sawyers Valley, 37 to 52 per cent.; Mahogany Creek-Glen Forrest, 27 to 50 per cent.; Kalamunda-Walliston, 24 to 45 per cent.; Clackline (one sample) 43 per cent.

Average high-grade rocks from Wooroloo (1) and Sawyers Valley (2) contain:—

	Al_2O_3	Fe_2O_3	TiO_2	CaO.MgO	Insoluble.	Ignition Loss.
(1)	43.39	17.72	1.46	Nil	13.40	24.04
(2)	51.82	9.35	.56	Nil	11.90	26.37

Graphite.—This mineral is found throughout the Pre-cambrian rocks of the State, but it is only the mineral which occurs in comparatively coarse flakes (over 0.1 millimetre) which is commercially valuable. Such graphite

* Beresofite, the name originally applied by E. S. Simpson to this mineral (Min. Mag. 19, 103) had previously been used for another mineral; Beresovskite is therefore substituted for it.

has been found in several places, notably in the Northampton mining district, and at intervals over a 300-mile east and west belt of country extending from the Oldfield River, west of Esperance, to the Donnelly River near Cape Leeuwin. The most important deposits along this belt are at Munglinup, Pallingup River and Kendenup.

In the Western Australian deposits no solid lumps of pure graphite are known similar to those found in Ceylon. The occurrences are of the Madagascar type, consisting of innumerable flakes and minute lenses of mineral along the planes of schistose igneous rocks. At the surface these are usually heavily impregnated with iron hydroxide and therefore incapable of concentration to the requisite minimum of 80 per cent. carbon. Below this gossan, which is never more than a few feet thick, the scaly graphite is found associated with bands of partly weathered rock which is easily concentrated, except in some instances where there is an intimate intergrowth of scales of mica and graphite.

The Government Laboratory is equipped with a model flotation plant for testing ores on commercial lines. Unless a yield is obtained of at least 10 per cent. of marketable flake, assaying 80 per cent. or over of carbon in scales not less than 0.1 mm. in diameter, an ore is considered valueless for the production of concentrates to be used in the crucible industry.

Some very good graphite has been got at Munglinup, a series of eleven samples showing a yield of 10.5 to 36.8 per cent. of flake with a maximum content of 93.2 per cent. of carbon and an average of 80 per cent. The Munglinup flake on the whole is coarser than that at Kendenup, where similar deposits have been opened up and a few tons of ore shipped abroad in the absence of any local dressing plant. The Kendenup deposits are close to the railway, only 50 miles from the port of Albany. The principal workings are on a band of weathered schist seven samples of which ran from 6 to 80 per cent. flake graphite. Concentrates from this mine have been very favourably received by crucible makers.

Beryl.—The use of this mineral in high tension electrical porcelain has recently been adopted. The mineral is a crystalline silicate found almost entirely in pegmatite veins, where it is usually associated with felspar of ceramic grade. In Western Australia it is found in several localities, notably Mt. Francisco, Wodgina, Yinnietharra, Poona, Melville, Balingup and Ravensthorpe. In all cases it would probably only pay to mine in conjunction with the associated felspar.

Andalusite, Kyanite and Sillimanite.—All of these are crystalline silicates of aluminium without water, which have been employed for the manufacture of special refractories and electrical porcelain in Europe and America. They are not common minerals, but in some parts of the world rock masses have been found consisting of 60 to 80 per cent. of these minerals and such rocks are used by ceramists in their entirety.

In Western Australia micaceous schists carrying in certain bands comparatively large masses of these highly refractory minerals are known.

In the lower Chittering Valley, 30 to 40 miles north-east of Perth, there is a very large area of sillimanitic and kyanitic rocks. A small prospect has been opened up at Goyamin Pool and from it 15 tons of 90 per cent. sillimanite taken out from segregations in a biotite schist alongside a dolerite dyke.

In the upper Chittering Valley, especially, there are large areas of kyanite rocks suitable for concentration.

At Clackline, 50 miles east of Perth, there is a large firebrick plant operating on a sillimanite fireclay.

At Wilgarup, 150 miles south of Perth, boulders of kyanite have been found, but not yet traced to their source. An appreciable quantity of these boulders has been collected and marketed.

Sillimanite bearing rocks are known to occur at Toodyay to a very limited extent, but no commercial exploitation of them has ever been attempted.

DESCRIPTION OF LABORATORY TESTS APPLIED.

The series of tests which have been applied to Western Australian clays was devised to satisfy the particular requirements of the times. These were designed to provide information of some practical value with apparatus that would not be too elaborate, spacious or costly.

The methods of testing any raw material are dependent on the methods of manufacture to be applied to it and its ultimate uses. The testing of clays, therefore, follows mainly on physical, rather than chemical, lines. Whilst clays are worked up in the raw state, the finished product has always passed through a process of burning. Having this in view, the series of tests is conveniently arranged under three headings:—

- (A) the determination of the properties of the raw clay;
- (B) the investigation of its behaviour during burning;
- (C) the determination of the properties of the burnt clay, the burning having been made at several different temperatures.

The complete list of tests applied was:—

A. Properties in the Raw State:

- (1) Chemical composition.
- (2) Mineral composition.
- (3) Mechanical composition or texture.
- (4) Plasticity.
- (5) Air shrinkage.
- (6) Tenacity when dry.

B. Each clay was then burnt under various conditions of time and temperature, and its behaviour in the kiln was noted, after which the third series of tests was applied, viz.:

C. Properties in the Burnt State:

- (1) Colour.
- (2) Fusibility.
- (3) Shrinkage.
- (4) Porosity.
- (5) Vanadium staining.
- (6) Strength.
- (7) Surface grain.

Details of the individual tests follow.

(A.1) *Chemical Composition*.—Complete chemical analyses were made of such clays as appeared likely to be used for pure white or cream ware. The results were mainly used to calculate the approximate mineral composi-

tion, which is of the highest value in predicting and explaining the properties during and after burning, and in calculating the requisite addition of fluxes to produce a good porcelain or semi-porcelain body, etc. The proportions of oxides of iron and titanium present are of interest in determining the cause of a yellowish tinge developed on burning certain white clays. The determination of the common salt present is of the highest importance in view of the very deleterious effect of this compound on clays, and was therefore made on every clay before a burning test was made. The total water soluble salts content was also determined.

(A. 2) *Mineral Composition*.—This was calculated from the complete analysis after microscopical examination of the different grades obtained by elutriation. The method of calculation adopted was as follows:—

Chlorine was calculated to sodium chloride. The remaining sodium and potassium were added together and calculated as mica $(\text{KNa})\text{H}_2\text{Al}_3\text{Si}_3\text{O}_{12}$. Titanium was calculated to ilmenite FeTiO_3 , doelterite, H_2TiO_3 , or to one of the mineral oxides TiO_2 according to the microscopic examination. The balance of the iron was stated as ferric hydroxide, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$. The alumina remaining was calculated to kaolin, $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$, and halloysite, the relative proportions of the two silicates being approximately estimated from the proportion of water and the Ashley plasticity figure. The balance of the silica was taken as quartz SiO_2 .

The results of this calculation may not always be rigidly accurate, but they are usually very close to the truth, and give figures of great practical value.

(A. 3). *Texture or Mechanical Composition*.—The particles composing the clay were divided into clay substance and grit, the latter subdivided into sizes over 30, 60 and 90 mesh and under 90 mesh. These corresponded approximately to particles over 0.60, 0.26 and 0.18 millimetre, and under 0.18 millimetre diameter.

The clay substance was determined by dropping 100 grams of air dry, 10 mesh, clay in a slow and oscillating stream into a 800 ml. beaker full of tap water ($\text{pH} 8.4 \pm$). It was stirred well to dissolve soluble salts and two-thirds of the liquid decanted after 5 minutes settling. It was filled up with water and allowed to soak overnight, and then washed by repeated decantation after 90 seconds settling, each time, at least two inches of fluid being left in the beaker for the first few decantations, and thereafter, one inch. After each decantation the residue was roughly swirled to break up composite particles. The grit remaining was dried and weighed, and then sifted in the three screens mentioned. The clay substance thus obtained was mainly kaolin and halloysite, but included some very fine particles of other minerals, particularly microscopic grains of mica.

It is to be noticed that dispersion of the clay particles is almost impossible if the water is poured on to the raw clay, especially if the latter is already damp.

Some hard clays with small amounts of secondary silica or carbonates required rubbing up with a rubber pestle after the first few decantations, in order to break up composite particles.

(A. 4) *Plasticity*.—This capacity for moulding or shaping without cracking or relaxing is the characteristic property of substances in the plastic state, which may be defined as a state of matter intermediate between true

solidity and true fluidity, a substance in the plastic state being resistant to deformation by gravity or other moderate force, but deformable without cracking by more intense human or mechanical pressure. Plastic substances are essentially two or three component systems, requisite components being a fairly rigid granular base with a viscous fluid lubricant filling the inter-spaces, the lubricant acting also as an adhesive. In the case of potters' clays the base consists of granules of quartz, mica and kaolin, whilst the lubricant is a colloidal suspension of halloysite, and probably other substances in water.

From the practical point of view, plasticity is of the highest importance, as the capacity of a clay mixture for fine moulding will depend upon the plasticity of its components. It is probably governed by several independent factors, the principal one being the proportion of colloids and water present, others the size and shape of the individual particles. Many methods have been suggested for obtaining a mathematical statement of this property, none of which is exact, and it appears as if the only ultimate test of plasticity is the discrimination of the practical potter.

Assuming, however, that within the limits found in most light coloured clays, the plasticity is directly proportional to the percentage of colloids present, and making use of Ashley's work on the adsorption of aniline dyes by clay colloids* an empirical "Ashley's figure" has been largely used as the guide to the relative plasticity of fine pottery clays. This figure was only adopted for use after tests made by an experienced potter showed conclusively that the "Ashley figure" placed a series of clays in the same order of relative plasticity as did the practical modelling test. This figure was found by measuring the adsorption of malachite green oxalate by the colloids of a fixed quantity of clay. The method adopted was as follows:—

One gram of coarsely crushed malachite green oxalate was placed in a 500 mls. wide-mouthed bottle with 400 mls. of distilled water, and 20 grams of the clay added to it. The mixture was then shaken well at intervals for two or three hours, to ensure that all the dye was dissolved, and that the hydrogels were completely saturated with water. The suspension was allowed to settle overnight. Ten mls. of the water were drawn off and diluted to 100 mls.; 10 mls. of this again diluted to 100 were compared colorimetrically with 10 mls. of a standard solution obtained similarly but without the addition of clay. If they exactly matched no adsorption had taken place. If, however, 10 mls. of the solution from the clay was matched by "x" mls. of the standard solution then $(10 - x)$ is a measure of the adsorption, and, expressed as centigrams of malachite green adsorbed by 20 grams of clay, was taken as the "Ashley figure."

Occasionally the Ashley figure exceeded 90. When this was the case, adsorption may not have proceeded to saturation point and the true figure may be over 100; a further 1 gram of malachite green oxalate was then added to the suspension and the shaking and settling repeated. Finally the solution was compared as before with the standard.

It would appear that the "Ashley figure" is vitiated by the presence of an appreciable amount of marly calcite, and to a less extent by colloidal ferric hydroxide, in both cases a high reading being obtained. The effect of the former when present was overcome by a preliminary shaking of the clay and water with 1 gram or more of sodium or potassium oxalate.

* *United States Geological Survey Bulletin* 388.

The "Ashley figures" given by typical classes of clay were:—

Abnormally quartzose or micaceous clays	.. ..	1 to 20
Fireclays and washed kaolins (China clays)	.. ..	20 to 40
Semiball clays	.. ..	40 to 70
Ball clays and red brick clays	.. ..	70 to 150
Fullers earths and bentonites	.. ..	Over 150

Preparation of Clay for Moulding.—The crude clay (about 10 lbs.) was first air dried and broken gently to pass a 10 mesh sieve. The content of salt was then determined, and if over 0.3 per cent., a preliminary washing of the clay by decantation was made to remove the greater part of it. After this the clay was filtered and again air dried, crushed lightly to pass a 10 mesh sieve and well mixed.

For moulding, about one pound of the dry clay was taken, and water worked into it until it was distinctly softer than was necessary to mould easily. After working by hand for about half an hour, the wet clay was set aside overnight in a damp place to mature, i.e., to completely swell the hydrogels. In the morning it was again kneaded, a little more water usually having to be added to bring it to a suitable state of plasticity for moulding. Small uniform test pieces were made in a steel cylinder filled with two loose discs and with two weep holes of one-eighth inch diameter in the side. To obtain the test pieces the loose bottom disc was put in the mould (lightly oiled) and a roll of plastic clay pressed in and cut off at the upper level of the mould. The loose top disc was then put on and pressed in about one-eighth inch by hand, after which the top and bottom were further pressed in by an ordinary hand bench vice until clay projected from each of the weep holes. The pressure was relieved, the bottom removed and the moulded cylinder of clay forced out by a plunger.

(A.5) *Air Shrinkage.*—The diameter of the test piece was that of the mould, viz., 38 mm., and the height was immediately measured in mm. at a marked spot by a sleeve micrometer. The test piece was then immersed in petrol to remove most of the oil picked up from the mould, and set aside to dry at air temperature. After drying for about a week the diameter of the briquettes was measured in two directions at right angles to one another, and the height measured at the previous point. The average linear shrinkage per cent. was calculated from these measurements.

If D_1 , D_2 and H were the original diameters (in two directions at right angles) and height and d_1 , d_2 and h were the dried.

Then air shrinkage per cent. was—

$$\frac{(D_1 + D_2 + H) - (d_1 + d_2 + h)}{D_1 + D_2 + H} \times 100$$

Air shrinkages measured on Western Australian clays varied from under 1 per cent. for highly siliceous or micaceous clays up to 17 per cent. for highly plastic clays, the figure rising rapidly with increase in hydrogels and decrease in stable crystalloids like quartz. Some typical figures were nil for a kaolinised porphyry, 1.3 per cent. for a kaolinised granite, 3.6 and 7.2 for sedimentary fire clays, 11.8 for a ball clay and 16.3 for a red brick clay. Any tendency to warp during drying was noted at this stage.

For all classes of ware, but particularly for hollow ware, it is necessary to know the air shrinkage as well as the fire shrinkage so as to make the necessary allowances for size in designing and modelling. An air shrinkage

above 8 per cent. introduces such large differences in size between the modelled and finished article, as well as leading to warping, that clays with this property must be mixed with more siliceous or more micaceous material, or grog (previously burnt clay of the same type), before use.

(A. 6). *Tenacity when Plastic and when Dry.*—These are both worthy of careful measurement. It is desirable that this should be done in a machine of the cement type, as the plastic strength of a body is of prime importance in throwing clay ware. No such determinations were made in any of the tests carried out in the Government Laboratory owing to the absence of the necessary equipment. The dry tenacity is also important from the point of view of the capacity of moulded ware to stand handling during transportation to and from the drying chamber, and whilst packing in saggars and stacking in the kiln.

As the necessary facilities for obtaining a figure were not available these characteristics were tested roughly on one of the test pieces by determining the ease with which the edges could be broken and the surfaces rubbed off by the fingers.

(B.) *Burning.*—A large number of semi-commercial burning tests lasting over several days was made in a special kiln. The experience gained showed that practically useful and closely comparable results could be obtained by burning the above described test pieces in an assay muffle furnace over considerably shorter periods. The main observed difference between the two tests was that in the kiln, owing to the more gradual increase in the temperature, there was less tendency to crack during burning, whilst the final body was slightly stronger and less porous than that produced in the small muffle furnace.

The standard temperatures chosen for these tests were (950° and 1000° centigrade for highly coloured clays), 1050° , 1150° , 1250° , 1350° and rarely 1400° . Higher temperatures than 1350° were seldom obtainable in a muffle furnace and were not required under the existing conditions of the trade in Western Australia as the manufacture of firebricks and fire lumps from local materials had already been well established. On the other hand special information was required in regard to our raw materials for making white ware and cream coloured ware (maximum temperature requirement about 1250°), vitrified sanitary ware (1350°) and roofing tile (1100°).

As the Department did not possess a pyrometer the indicators used were:—

- 950° Pure silver wire in a small coil resting in a depression of the surface of the briquette. Melting point 961°
- 1000° Alloy of 40% gold, 60% silver, in sheet. Melting point 1003° .
- 1050° Pure gold sheet used in the same way. Melting point 1062° .
- 1150° Seger cone No. 3a.
- 1250° Seger cone No. 8.
- 1300° Seger cone No. 10.
- 1350° Seger cone No. 12.

After steam drying the test pieces were heated for seven hours in a hot air oven to a maximum temperature of 210°C. , followed by heating in an electric furnace for seven hours to a maximum temperature of 900° and then for a further seven hours to 1050°C. , fourteen hours to 1150° , 21 hours to 1250° and 28 hours to 1350° . It was necessary to allow the furnace

to cool down overnight after each seven hours burning, those briquettes burnt to the desired temperature being taken out of the cold furnace in the morning.

There was little to note regarding the behaviour of the clays during the actual burning except in three regards. Highly plastic clays often cracked during the earlier stages of heating usually below the dull red. This could be obviated by a thorough steam drying followed by slow heating in a hot air oven before burning, except in a very few instances of extremely plastic clays obviously unsuited for commercial burning without admixture with more siliceous and porous material. Highly salty clays could be seen to blister on the surface at temperatures above 1000° , and in some cases to swell up into pumice-like bodies. Finally, ferruginous clays were occasionally heated to a point at which they could be seen to start flowing.

(C. 1) *Colour of Burnt Body*.—The first test to be applied to the burnt briquette was to examine its colour very carefully. In all but a few of the very purest white clays this was found to vary with the temperature of burning, being usually darker or more pronounced as the temperature of burning increased. Thus a clay which burnt to a pure white at 1050° might show a creamy tinge at 1150° and a still stronger cream tint at 1250° and 1350° . A clay which was only pale cream when burnt at 1050° would perhaps be a distinct buff, after heating to 1250° and 1350° . A coloured clay burning to a light red at 950° might be dark red after 1050° , liver coloured after 1150° and almost black after 1250° .

The colour assumed by a clay when burnt particularly at or about 1150°C. , is one of the first characters to determine its range of utility. For white ware, the most valuable weight for weight of all ware, only clays burning at 1150° to a white or at most a very pale cream can be utilised, and other things being equal, the clay producing the whitest body at this temperature is the most valuable. For clays for white ware and cream coloured ware therefore, this temperature was chosen as the standard temperature for comparison. The white ware clays were graded into (1) pure white; (2) good white; (3) creamy white; (4) greyish white, according to their colour after burning at 1150° ; the cream ware clays into (5) light cream; (6) strong cream; (7) light buff; (8) strong buff; (9) pinkish buff, after burning at the same temperature. Finally the strongly coloured clays were classified according to the colours developed at 1050° into (10) light and dark grey; (11) terra cotta and light red; (12) dark red and brown.

The selection of a standard for "pure white" presented some considerable difficulty. So-called white papers are all quite appreciably tinted, as also are all porcelain and semi-porcelain tiles, etc. Finally chemically precipitated calcium carbonate, precipitated basic magnesium carbonate, pure calcined magnesia, and a very pure surface magnesite in powder were used for comparison, especially the first and second named.

For all red and terra cotta ware a lower temperature of comparison, viz., 1050° was chosen, as such ware (house brick, agricultural drain pipe, roofing tile, etc.) is burnt somewhere round about this temperature. The briquettes burnt at higher temperatures were useful for determining the temperature required to produce clinkered or vitrified brick or tile, and the possible utility of the clay as a flux for stone ware, etc.

(C.2) *Fusibility*.—The temperatures at which some or all of the constituents melt to form a porcelain, slag or glass are factors of great practical importance. Clay mixtures seldom or never completely melt at a

definite point as do metals or ice, but usually show a progressive softening and increase of vitrification over a long range of temperature. To record the behaviour of a clay in this respect three stages were noted, viz.:—

- (1) Incipient vitrification: This was the temperature at which the cold body first showed a hardness greater than that of pen-knife steel, indicating that the most fusible of the constituents had melted and bound the whole clay into a steel hard, but porous, mass. This frequently occurred at 1200° to 1250° when much mica or other flux was present.
- (2) Advanced vitrification: This was the point at which the body had not only become steel hard but, by slight internal flow, had obliterated most of the pores, reducing the total porosity to less than 5 per cent.
- (3) Flowing temperature: The point at which the briquette or other object showed general flow to the extent of losing its original outline.

(C.3) *Fire Shrinkage*.—This important factor was determined by micrometer measurements of the burnt briquette or other test piece in a similar way to that described under Air Shrinkage (p. 208). The observed linear shrinkages ranged from a small negative amount (i.e., a slight expansion) up to as much as 17 per cent. in the case of Woodlupine ball clay (No. 2333E).

Very siliceous clays show only a minute shrinkage, or even a slight expansion rather than a shrinkage, between 800° and 1050° because of the alteration of quartz to tridymite. As an example No. 1860E, a granitic fire clay from Glen Forrest, with an air shrinkage of 3.9 per cent., showed a fire expansion of 0.6 per cent. at 1150° , and an expansion of 0.1 per cent. at 1350° . A fine grained siliceous clay from Kanowna (No. 1732E) showed only 0.1 per cent. shrinkage at 1050° , 0.3 at 1150° , and 5.1 at 1250° .

On the other hand a pure white and almost quartzless kaolinised dolerite from Glen Forrest (No. 1859E) with an air shrinkage of 9.2 per cent., showed an additional 4.6 per cent. at 1050° , 8.9 at 1150° , 14.4 at 1250° and 16.5 at 1350° . The corresponding figures for a similar Wagin clay (9000E), used commercially as a china clay, were 4.2 in air; 3.2, 4.8, 12.8 and 16.6 in the fire.

These high shrinkages are in practice avoided by suitable additions of finely ground flint or other highly siliceous or previously burnt materials.

The approach of the "flowing temperature" is indicated usually by a sudden increase in shrinkage. This is followed by a slight increase in volume when the viscous stage is actually reached, owing to the expansion of included gases, which are unable to escape once the surface has been completely converted into a viscous fluid.

(C. 4) *Porosity*.—The porosity of a burnt body is brought about by the independent shrinkages of its component particles during drying and burning. It varies with the temperature, decreasing as the latter rises, and falling to a very low point as complete vitrification is approached. It is determined numerically in order to decide whether the clay will give a vitrified impervious, or semi-vitrified body when burnt alone or whether fluxes will have to be added to effect this. In the case of tile and brick bodies exposed to the weather the porosity figures indicate their capacity to keep out damp and resist abrasion and should not exceed 15 per cent. Finally the

porosity figure at the highest temperature of burning (1350°) is an indication of the capacity of a fire clay to stand a higher temperature without failing. For example a Collie bedded clay (No. 1575E) showed a porosity of 25.3 at 1350° indicating that it was far below its melting point at this temperature.

The porosity is stated in terms of grammes of water absorbed per 100 grammes of burnt body. It was determined by weighing the dry burnt body, immersing it slowly in water, and alternately heating to boiling, and cooling to air temperature, three times. The saturated briquette was then again weighed and the percentage of absorbed water calculated.

Some characteristic examples of porosity figures are:—

No.	Clay.	Locality.	1050° .	1150° .	1250° .	1350° .	1400° .
1388E	Stoneware ...	Mundijong ...	16.0	7.2	6.3	3.2	Nil
1575E	Sed. fireclay ...	Collie ...	34.5	33.6	31.2	25.3	?
4166E	China clay ...	Kunjin ...	38.2	35.5	24.5	9.2	?

(C. 5). *Vanadium Staining*.—It is as the briquette dries, after saturation with water during the porosity test, that any staining due to water soluble vanadium salts becomes apparent. It appears as a canary yellow, orange yellow, or greenish yellow stain on the upper surface of the dried briquette, and occasionally is very pronounced. The white doleritic clays from Quairading-Jacobs Well district show it quite strongly. Such a stain might well affect the colour of the glaze of finished ware.

(C. 6). *Strength*.—The strength of a burnt-body should be determined instrumentally to render the testing of a clay complete. In the series of tests carried out in the Government Laboratory a rough indication of it was obtained by scratching the surface with the finger nail or penknife and by endeavouring with the hands only, to chip off fragments from the arrises.

(C. 7). *Surface Grain*.—The final test applied to the burnt body was to examine closely the texture of the surface, noting whether it was extremely fine and smooth, or on the other hand, quite rough, granular and porous, or whether it had some intermediate quality. From this one could judge what sort of finish might be expected in articles made from the unground and unscreened clay.

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APPENDIX I.

Analyses of Western Australian Clays.

APPENDIX II.

Classification of Western Australian Clays.

APPENDIX III.

Localities of Clays Tested.

APPENDIX IV.

Physical Tests of Best Western Australian Clays.

APPENDIX I.
ANALYSES OF WESTERN AUSTRALIAN CLAYS.

No.	...	...	...	1	2	3	4	5	6	7	8	9	10
Locality	...	...	...	Yuna.		Bolgart.	Burabadji.	Armadale.		Cardup.			Campion.
Economic Class	...	...	...	I. A, Stone Clay.	IV. A(a), Ball Clay.	X. A(b), Stoneware.	II. A(a), Ball Clay.	I. A(d), China Clay.	Soft Slate.	Soft Slate.	Weathered Slate.	III. A(a), Ball Clay.	Miloschite.
SiO ₂	...	...	...	% 72.86	% 71.22	% 70.52	% 43.10	% 52.39	% 67.20	% 73.42	% 70.06	% 51.25	% 54.04
Al ₂ O ₃	...	...	...	16.87	17.69	17.27	39.56	32.26	15.06	12.51	18.29	34.19	30.27
Fe ₂ O ₃	...	...	...	.94	.27	1.70	.69	.56	n.d.	3.81	1.17	.64	.16
FeO	...	...	...	...	...	...	...	...	4.14	1.56	.40	...	.14
MnO	...	...	...	Nil	Nil	Nil	Nil	Nil	.05	.43	.07	...	tr.
MgO	...	...	...	.43	.30	.50	Nil	.16	2.43	1.91	.45	Nil	.31
CaO	...	...	...	Nil	.31	tr.	Nil	.04	.11	Nil	Nil	Nil	Nil
Na ₂ O	...	...	...	.22	.26	.14	.17	.29	.42	.86	.11	.16	.23
K ₂ O	...	...	...	1.16	.63	1.30	.64	.54	4.94	3.02	3.72	tr.	.14
NaCl	...	...	...	...	1.14	.61	.13	.58	tr.	tr.	.48	.15	tr.
TiO ₂	...	...	...	.77	.46	.82	.44	.23	.46	.25	.74	.45	.31
CO ₂	...	...	...	...	...	...	...	...	Nil	.02	.02	Nil	Nil
P ₂ O ₅	...	...	...	n.d.	.25	.20	Nil	...	.01	.12	0.6	...	Nil
SO ₃	...	...	...	.33	n.d.	.22	Nil	...	...	...	...	...	n.d.
H ₂ O +	...	...	...	5.62	6.91	6.24	14.49	11.69	3.39	2.38	4.17	12.26	11.89
H ₂ O —	...	...	...	.98	.51	1.28	1.03	1.42	.29	.12	.86	1.23	2.16
Humus	...	...	...	...	...	...	...	...	.46 †	.03 †	Nil †	Nil	Nil
Others	...	...	...	...	.43*	...	.08*	...	1.07 †	.00 ‡	.00	.03*	.80 §
Total	...	...	...	100.18	100.38	100.80	100.33	100.16	100.03	100.44	100.60	100.36	100.45
Analyst	...	...	...	Webb.	Gillies.	Webb.	Gillies.	Bowley.	Le Mesurier.	Murray.	Murray.	Bowley.	Hill.
Appendix IV. No.	...	...	...	...	...	...	39	24	...	...	...	71	...

* Water soluble salts. † Pyrite. ‡ Graphite. § Cr₂O₃ (In 10, V₂O₅ nil).

APPENDIX I.—ANALYSES OF WESTERN AUSTRALIAN CLAYS—continued.

No.	...	...	...	11	12	13	14	15	16	17	18	19	20
Locality	...	...	...	Clackline.	Collie.	?	III. A(d), Fire Clay (Shale).	?	Dongara.	Elgin.	I A.(a), Levigated China Clay.	II A.(a), Fire Clay.	Stinkwell.
Economic Class	...	...	...	II. D, Kaolinised Sillimanite Schist.	?	Fire Clay (Shale).	III. A(d), Fire Clay (Shale).	?	?	II A.(a), Ball.	I A.(a), Levigated China Clay.	II A.(a), Fire Clay.	II A.(a), Semi-ball.
SiO ₂	...	...	...	% 63.83	% 51.55	% 51.95	% 54.31	% 62.74	% 45.74	% 49.08	% 47.57	% 52.19	% 48.07
Al ₂ O ₃	...	...	...	26.24	33.25	29.58	28.32	13.32	11.01	34.58	37.93	34.18	35.96
Fe ₂ O ₃	...	...	...	.60	.43	3.40	1.23	5.56	4.26	.43	.31	.64	1.00
FeO	...	...	...	Nil	Nil	n.d.	n.d.	n.d.	n.d.	Nil	Nil	Nil	Nil
MnO	...	...	...	Nil	Nil	tr.	.58	.45	.33	Nil	Nil	Nil	.01
MgO	...	...	...	.22	.40	1.01	.33	1.39	1.38	Nil	Nil	Nil	.28
CaO	...	...	...	Nil	.09	tr.	Nil	1.30	14.86	.04	Nil	Nil	.13
Na ₂ O	...	...	...	.09	.31	1.09	.11	.66	.54	.25	.11	.10	.06
K ₂ O	...	...	...	1.76	.11	.63	.39	3.46	2.09	.75	.58	.51	.54
NaCl	...	...	...	.03	...	present	.69	Nil	Nil	.36	Nil	.15	.08
TiO ₂	...	...	...	.58	2.19	...	.56	.70	.51	.67	.22	.34	1.26
CO ₂	...	...	...	.03	...	...	.26	.38	12.10	Nil	Nil	Nil	Nil
P ₂ O ₅	...	...	...	.04	...	...	n.d.	...	...	n.d.	n.d.	...	.05
SO ₃	...	...	...	.02	...	...	Nil	...	...	Nil	Nil	...	Nil
H ₂ O +	...	...	...	6.15	10.41	11.23	9.61	6.46	4.68	12.26	12.36	11.38	12.31
H ₂ O —	...	...	...	.60	.90	.54	2.90	4.16	2.68	1.43	1.07	.50	1.02
Humus	...	...	...	Nil	Nil	present	1.10	...	...	Nil	Nil	Nil	Nil
Others	...	...	...	...	V ₂ O ₅ tr.	...	.16*	...	...	.11*	...	.02*	...
Total	...	...	...	100.19	99.64	99.43	100.55	100.58	100.18	99.96	100.15	100.01	100.77
Analyst	...	...	...	LeMesurier.	Williams.	Simpson.	Gillies.	Webb.	Webb.	Gillies.	Simpson.	Gillies.	LeMesurier
Appendix IV. No.	...	...	...	...	...	...	...	...	...	42	3	43	45

* Water soluble salts.

APPENDIX I.—ANALYSES OF WESTERN AUSTRALIAN CLAYS—continued.

No.	...	...	...	21	22	23	24	25	26	27	28	29	30
Locality	...	...	...	Jacob's Well.	Kalamunda.	Kunjin.	Moora.	Mt. Kokeby.	Mujar.	Newlands.	Perth.	Wagin.	
Economic Class	...	...	...	I. C(d), Fire Clay.	III. A(a), Ball.	IA. (a), China Clay.	? Shale.	I. A(a), Semi-ball.	III. A(c), Semi-ball Refractory.	VI. A(a), Stoneware White.	XII. A(a), Stoneware Red.	XI. A(b), Terra-cotta.	I. A(a), China Clay.
SiO ₂	...	...	...	% 48.06	% 48.69	% 46.51	% 50.34	% 51.43	% 61.92	% 65.45	% 61.39	% 56.80	% 45.57
Al ₂ O ₃	...	...	...	36.83	29.19	38.12	31.97	33.94	26.09	21.53	18.12	19.88	38.28
Fe ₂ O ₃	...	...	...	.11	1.77	.40	2.68	.93	.75	.94	8.74	7.16	.56
FeO	...	...	...	Nil	.56	Nil	n.d.	n.d.	...	.12	.12	...	.14
MnO	...	...	...	tr.	.04	Nil	...	Nil	...	.09	.11	...	Nil
MgO	...	...	...	.18	.38	Nil	.86	Nil	.27	.71	1.00	.41	.14
CaO	...	...	...	.06	.06	.09	.16	Nil	Nil	Nil	tr.	.74	Nil
Na ₂ O	...	...	...	.17	.01	.12	.22	.37	.26	.31	.40	2.25	.20
K ₂ O	...	...	...	.58	.16	.32	2.66	.36	.74	1.69	1.98	1.92	.91
NaCl	...	...	...	.24	.03	.16	...	.17	tr.	...	...	.46	.27
TiO ₂	...	...	...	.98	4.52	.62	...	.51	.54	n.d.	n.d.	...	.30
CO ₂	...	...	...	Nil	.11	Nil	...	...	...	...	...	...	.02
P ₂ O ₅	...	...	...	...	.02	...	...	...	Nil	...	...	...	.14
SO ₃	...	...	...	...	.02	.05	...	.24	...	...	...	...	.01
H ₂ O +	...	...	...	12.75	12.10	13.68	9.73	11.32	8.64	7.34	6.38	10.50	13.11
H ₂ O -	...	...	...	.72	2.07	.50	1.15	.78	1.48	1.96	2.16	.47	.56
Humus	...	...	...	Nil	.24	Nil	...	...	...	...	...	...	.22
Others	...	...	...	...	.09*	...	...	.06†	...	...	...	...	Nil
Total	...	...	...	100.68	100.05	100.57	99.78	100.11	100.69	100.14	100.40	100.59	100.43
Analyst	...	...	...	Bowley	Grace	Bowley	Bowley	Murray	Murray	Simpson	Simpson	Robertson	Saw
Appendix IV No.	...	...	...	35	74	5	...	7	...	...	...	...	8

* Cr₂O₃, 0.02; V₂O₅, 0.07.

† Water soluble salts.

APPENDIX I.—ANALYSES OF WESTERN AUSTRALIAN CLAYS—continued.

No.	...	...	31	32	33	34	35	36	37	38	39	40	41
Locality	...	...	Westonia.		Wilga.		Kalgoorlie.		Kanowna.				
Economic Class	{		Miloschite.		I. A(c), Refractory Ball Clay.	XII., Terra- cotta.	XI., Kaolinised Lodestuff.	I. A(c), Cornish Stone.	III. A(a), Stone- ware.	I. A(a), Cornish Stone.	I. B, Cornish Stone.	III. A(a), Cornish Stone.	A., Auriferous Alluvium.
SiO ₂	...	...	% 46.38	% 45.98	% 56.15	% 63.61	% 56.85	% 69.41	% 45.04	% 66.94	% 77.23	% 77.21	% 44.16
Al ₂ O ₃	...	...	37.57	38.53	30.92	15.45	13.66	21.08	37.76	21.96	15.96	15.17	30.38
Fe ₂ O ₃	...	...	.06	.05	.33	2.90	11.79	.24	.44	.15	traces	.13	4.44
FeO	...	...	Nil	Nil	...	3.10	5.38	Nil	Nil	...	...	...	...
MnO	...	...	Nil	Nil	...	.14	Nil	Nil	Nil	...	...	...	...
MgO	...	...	.36	.19	tr.	2.66	2.69	tr.	.15	.03	...	.15	Nil
CaO	...	...	Nil	Nil	Nil	Nil	.47	.02	Nil	Nil	...	Nil	.70
Na ₂ O	...	...	.04	.02	.35	.43	.97	.14	3.77	.67	...	1.00	.53
K ₂ O	...	...	.07	.05	1.05	4.87	1.50	2.91	1.22	2.19	.14	2.41	1.05
NaCl	...	...	Nil	Nil	.12	tr.	.10	.31	1.42	.88	2.74	...	.33
TiO ₂	...	...	Nil †	Nil †	.62	.76	1.51	.14	1.06	.20	...	.79	...
CO ₂	...	...	Nil	Nil	Nil	.04	.08	Nil	Nil	Nil	...	.24	3.74 ?
P ₂ O ₅	...	...	n.d.	n.d.	n.d.	.22	.35	n.d.	n.d.	n.d.	...	...	...
SO ₃	...	...	n.d.	n.d.	n.d.	n.d.	.10	n.d.	(.31)	.05 ¶	...	...	...
H ₂ O +	...	...	13.75	13.91	10.53	4.20	4.00	5.32	7.93	6.70	3.36	2.63	11.80
H ₂ O —	...	...	.98	.89	.53	1.77	.58	.42	.92	.26	...	.10	3.81
Humus	...	...	Nil	Nil	...	.28	Nil	Nil	Nil	Nil	...	...	...
Others	...	...	1.22 ‡	1.01 ‡	.06 *	tr. §	.06 ¶	.07 *	.41 *	.25 *	...	.25 *	...
Total	...	...	100.43	100.63	100.66	100.43	100.03	100.04	100.12	100.28	99.43	100.09	100.94
Analyst	...	...	Simpson.	Simpson.	Gillies.	Murray.	Simpson.	Gillies.	Bowley.	Gillies.	Gillies.	Rowledge.	Williams.
Appendix IV., No.	...	...	...	...	23	...	...	20	1-75	4	...	...	...

* Water soluble salts.

† Rutile 0.57 deducted from 31; Rutile 0.32 deducted from 32.

‡ In 38 SO₃ as alumite, 0.05; also 0.08 in water soluble salts. In 40 SO₃ as alumite, 0.01; also 0.06 in water soluble salts.¶ Cr₂O₃; § FeS₂.|| Cr₂O₃, 0.06;

APPENDIX II.

CLASSIFICATION OF WESTERN AUSTRALIAN CLAYS.

Class	I. ....	....	Pure White (Colour after 1,150°C.).
Class	II. ....	....	Good White (do.)
Class	III. ....	....	Creamy White (do.)
Class	IV. ....	....	Greyish White (do.)
Class	V. ....	....	Light Cream (do.)
Class	VI. ....	....	Strong Cream (do.)
Class	VII. ....	....	Light Buff (do.)
Class	VIII. ....	....	Strong Buff (do.)
Class	IX. ....	....	Pinkish Buff (do.)
Class	X. ....	....	Dark Grey (do.)
Class	XI. ....	....	Terra Cotta and Light Red (after 1,150°C.).
Class	XII. ....	....	Dark Red and Brown (do.)

Sub Class	} for all Classes.	A.	Clay substance + finest grit over 90 per cent.			
		B.	Do.	do.	80—90	„
		C.	Do.	do.	70—80	„
		D.	Do.	do.	60—70	„
		E.	Do.	do.	50—60	„
		F.	Do.	do.	40—50	„

APPENDIX III.

LOCALITIES OF CLAYS TESTED.

Locality.	Registered No. and Classification of Clays.	Remarks.
Albany ...	7897 (IIIC.)	
Armadales ...	5109/33 (IIA.), 4584 (XA.)	
Arthur River ...	7501 (IIIA.)	
Balkuling ...	9637 (IIA.), 6635 (IID.), 1329/23 (IIIA.)	
Balla Balla ...	7901 (IIA.)	
Bannister ...	1833 (VA.)	
Bardce ...	2294/25 (IIIA.)	
Bassendean ...	4370 (XIIA.), 2007/33 (VIIIA.)	
Beenup ...	... ..	See Cardup.
Bellevue ...	1862 (IIID.)	
Berring ...	8837 (IIB.), 8876 (IIB.)	
Beverley ...	1972 (IIIA.)	
Bibilup ...	4939/29 (IID.), 4938/29 (IVA.)	
Boddington ...	2308/25 (IIIA.), 1964/25 (XIIA.)	
Bolgart ...	1555 (IIA.)	
Boulder ...	... ..	See Kalgoorlie.
Boyanup ...	1692 (XIC.), 1691 (XIIC.), 1690 (XIIIE.)	
Boyup Brook ...	1121/25 (IIC.), 1120/25 (IIIC.)	
Bridgetown ...	2103 (XIIC.)	
Broad Arrow ...	534/24 (IIB.)	
Brookton ...	2794 (IIA.)	
Bullaring ...	2728/23 (IID.), 2729/23 (XIID.), 2727/23 (XIIIE.)	
Bullsbrook ...	467/24 (XIIA.)	
Burabadgi ...	2457 (IA.)	
Burswood ...	277/24 (XIIA.)	
Busselton ...	80/27 (IIA.), 1584/25 (IIB.), 2531/28 (XIIIC.), 2530/28 (XIID.), 2532/28 (XIID.)	
Calcarra ...	1762 (ID.)	
Cannington ...	2019 (XIIIE.)	
Capercup ...	3197/33 (IIIA.)	
Cardup ...	7510 (IB.), 3819 (IIIA.), 7797 (IIIA.), 7190 (VA.), 7511 (VID.)	
Carmel ...	1407 (VIIC.), 1479 (XC.)	
Chidlow ...	2527 (VE.)	
Clackline ...	2741/26 (IA.), 2742/26 (IIX.), 2190/27 (IIIA.), 2567/24 (IIIX.), 2569/24 (IIIX.), 2570/24 (IIIX.), 2573/24 (IIIX.), 2576/24 (VIIIX.)	
Collie ...	1471 (IA.), 1646 (IA.), 1899 (IA.), 6702 (IA.), 288/25 (IA.), 1575 (IIA.), 5598 (IIA.), 5661/33 (IIA.), 8232 (IIC.), 1384 (IIIA.), 1472 (IIIA.), 1516 (IIIA.), 6703 (IIIA.), 6704 (IIIA.), 3886/27 (IIIA.), 1653 (IVC.), 5597 (VA.), 1698 (VIIB.), 7113 (VIIIA.), 468/24 (IXA.), 5207 (XA.), 5744 (XA.), 5745 (XIA.), 1514 (XIIA.), 5739 (XIIA.), 5746 (XIIA.), 5596 (XIIIB.)	
Coolgardie ...	3455 (IIA.), 1831 (XIA.)	
Coolup ...	1429 (XIIA.), 2039 (XIIA.), 1423 (XIIC.), 1424 (XIIIE.)	
Cranbrook ...	1464 (VIIIA.)	
Cunderdin ...	70/25 (IB.)	
Dangin ...	1579/26 (IA.)	
Darlington ...	... ..	See Glen Forrest.
Denmark ...	1408 (VIC.), 1757 (VIIA.), 1756 (IXB.), 1891 (IXB.)	
Donnybrook ...	1513 (IID.), 4587 (VD.)	
Dowerin ...	7177 (IID.)	
Duranillin ...	3078/24 (IIA.)	

APPENDIX III.—*continued*.
LOCALITIES OF CLAYS TESTED—*continued*.

Locality.	Registered No. and Classification of Clays.	Remarks.
Dwellingup ...	435/27 (IIA.)	Includes Darlington.
Elgin ...	1658 (IIA.)	
Ferguson ...	1546 (IA.)	
Galena ...	5280/32 (IIB.)	
Gingin ...	1400 (IXA.)	
Glen Forrest ...	3045 (IA.), 1859 (IIA.), 3514 (IIA.), 1861 (IID.), 1900 (IID.), 1743 (IIID.), 3513 (IIID.), 1860 (IIIF.), 3315 (VB.), 2196 (VD.), 2445 (VD.)	
Goomalling ...	701/32 (IA.), 1753 (IIA.), 8543 (IIA.), 5391/31 (IIA.), 5390/31 (IIIA.)	
Gosnells ...	2073/24 (IVB.), 2074/24 (VIB.), 2075/24 (XIIA.)	
Greenmount ...	4362/29 (XIIC.)	
Gutha ...	10221 (IIA.)	
Harvey ...	1453/27 (IIID.)	Includes Boulder.
Jacob's Well ...	1922 (IC.), 2016 (IIIA.)	
Jandakot ...	2923 (XIIC.)	
Jimperding ...	5107/34	
Kalamunda ...	4160 (IB.), 4158 (IIA.), 4159 (IIA.), 1390 (IIB.), 1550 (IIB.), 2241 (IIIB.), 4161 (?C.), 4162 (?E.)	
Kalgoorlie ...	1470 (IA.), 1697 (IA.), 1767 (IA.), 2117 (IIA.), 4340 (IIA.), 1013/29 (IIA.), 2100 (IIIA.), 4183 (IIIA.), 2101 (IIIB.), 4036 (III?), 1736 (IVA.), 2102 (IVA.), 3622 (VA.), 1832 (VIA.), 4035 (VIA.), 3250 (VIIA.), 1549 (XC.), 2199 (XIA.), 2281 (XIA.)	
Kanowna ...	2051 (IA.), 1732 (IB.), 2903/27 (IIA.), 2609/27 (IIA.), 1393/28 (IIA.), 2052 (IIB.), 2050 (IIIA.), 1394/28 (IIIA.), 1853 (IVA.), 1854 (VIA.), 1855 (VIB.), 1856 (XIB.), 1852 (XIIA.), 1898 (XIIA.)	
Kelmscott ...	2207 (VIB.), 2160 (XIC.), 2197 (XIIB.),	
Kendenup ...	1592/26 (IIB.)	
Kojonup ...	9261 (IIA.)	
Kondut ...	1766 (IIIE.)	
Kundip ...	1966/25 (VA.), 1965/25 (VA.)	See also Collie.
Kunjin ...	4166E (IA.), 4222E (IA.)	
Maddington ...	7260 (IIID.)	
Mambellup ...	7404 (XIA.)	
Manjimup ...	8043 (IIIA.)	
Meckering ...	195/26 (IA.)	
Merredin ...	4062 (XIB.), 1074/23 (XIIC.)	
Minnivale ...	1634/29 (IID.)	
Moora ...	1659 (XIIA.)	
Mt. Hardy ...	1687/26 (IIA.)	
Mt. Helena ...	563/31W (IIA.), 1041/31 (IIB.), 563/31 (IID.)	
Mt. Kokeby ...	1362 (IA.), 1430 (IA.), 3385 (IIA.), 2498/30 (IIA.), 3611 (IIIA.)	
Mujar ...	1389 (IIIA.)	
Mundijong ...	3307/24 (IVB.), 1388 (XIIA.), 2038 (XIIA.)	
Narrogin ...	8341 (IIID.), 8340 (XIIB.), 8339 (XIIC.)	
Newlands ...	3062 (VIA.), 3061 (XIIA.), 3063 (XIIA.)	
Ora Banda ...	2648/26 (IIIA.)	
Piawaning ...	8974 (IA.), 6322 (IIIA.)	
Pingelly ...	454/24 (IC.), 457/24 (IB.), 1982/29 (IID.), 1427 (IIID.), 456/24 (XD.), 458/24 (XE.), 455/24 (XE.), 1428 (XIID.)	
Pingrup ...	1463/25 (IA.) 444/25 (IIIC.)	
Pinjarra ...	2629 (IIIE.)	
Popanyinning ...	1592 (IVD.), 1810/23 (XIIA.)	

APPENDIX III.—*continued*.
LOCALITIES OF CLAYS TESTED—*continued*.

Locality.	Registered No. and Classification of Clays.	Remarks.
Quairading ...	2222/23 (IA.)	<i>See Glen Forrest.</i>
Ravensthorpe ...	2536 (IIIC.)	
Smith's Mill ...	... ..
Tambellup ...	8233 (IIIA.), 3396 (VIIA.)	
Tenterden ...	2055 (IIE.), 2112 (IIE.), 2046 (IIF.), 2749/27 (IIIB.), 2045 (XIC.), 8482 (XIIA.), 8483 (XIIA.)	
Three Springs ...	1970 (ID.), 3176 (I?), 3174 (IID.), 3175 (IID.), 2010 (XIIA.), 2009 (IIIC.)	
Toodyay ...	198/31 (IXB.)	
Totadgin ...	8073 (IXD.)	
Victoria Park ...	2162 (XIIA.), 2161 (XIIB.)	
Wagin ...	9000 (IA.), 2399/31 (IA.), 2626/23 (XIIC.)	
Walebing ...	2166 (IIIE.)	
Wannamal ...	1854/32 (IIIA.)	
Wardering ...	7169 (IIIB.)	
Warooka ...	1396 (XIA.)	
Wicherina ...	7717 (XIA.)	
Wilga ...	2111 (IA.)	
Woodlupine ...	8879 (IIIA.), 8880 (IIIA.), 8881 (IIIA.), 2333 (VIA.)	
York ...	7503 (XIIB.), 7502 (XIID.), 7504 (XIID.), 7357 (XIID.)	
Youraling ...	8537 (IIA.)	
Yuna ...	1568 (IIIA.), 1569 (IVA.), 8788 (VIA.), 8906 (VIA.), 1570 (XA.), 1979 (XA.), 4132 (XIA.)	

APPENDIX IV.
PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS.
N.B.—In this Table the figure for plasticity is that obtained by Ashley's method using malachite green dye.
In the colour scheme p.w. is pure white, g.w. is good white, cr. w. is creamy white.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IA. (a)—											
1	Clackline Loc. 171	Refractory china clay	C.S. 91.9 — 90 7.9 + 60 .1	17	% 5.2	°C. 1,050 1,150 1,250 1,350	% 3.4 5.4 6.6 10.7	% 27.2 25.8 22.3 13.5	p.w. p.w. p.w. cr. w.	..... ..... ..... Incipient	
2	Collie C.M.L. 245	Plastic fireclay	C.S. 99.2 — 90 .5 — 60 .3 + 60 tr.	52	6.6	1,050 1,150 1,250 1,350	.5 5.1 5.6 9.9	54.5 44.5 45.4 34.1	p.w. p.w. cr.w. cr.w.	..... ..... Incipient	Much coaly matter.
3	Glen Forrest, Statham's Pit	Levigated china clay	C.S. 100.0 — 90 — — 60 — + 60 —	28	7.1	1,050	5.3	23.1	p.w.	No vitrification	Prepared from kaolinised granite. Analysis No. 18.
4	Kanowna Alumite, P.A. 506	Fluxing clay (Cornish stone)	C.S. 91.5 — 90 4.3 — 60 2.8 + 60 1.4	20	2.6	1,050 1,150 1,250 1,350	.9 2.2 5.1 6.0	29.7 27.3 20.5 14.7	p.w. p.w. p.w. cr. w.	..... ..... Incipient	Analysis No. 38.
5	Kunjin Loes, 12446/7	China clay	C.S. 95.2 — 90 4.0 — 60 .4 + 60 .4	20	2.9	1,050 1,150 1,250 1,350	4.1 4.6 9.6 16.4	36.6 35.3 22.3 13.1	p.w. p.w. p.w. cr. w.	..... ..... Incipient	Analysis No. 23.
6	Meckering Loc. 22233	Refractory ball clay	C.S. 90.3 — 90 9.6 — 60 .1 + 60 tr.	78	8.3	1,050 1,150 1,250 1,350	2.2 3.6 12.0 13.6	31.6 28.8 14.2 10.1	p.w. p.w. cr. w. cream	..... ..... Incipient	Black spots at 1,350°.
7	Mt. Kokely Loc. 16114	Semi-ball	C.S. 91.9 — 90 7.8 — 60 .2 + 60 .1	50	5.5	1,050 1,150 1,250 1,350	8.6 9.9 13.4 11.8	28.6 24.7 17.0 11.3	p.w. p.w. p.w. g.w.	..... ..... Incipient	Analysis No. 25.

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IA. (a)— <i>continued</i> .											
8	Wagin Loc. 3533	China clay	% C.S. 90.7 — 90 9.1 — 60 .1 + 60 .1	24	% 4.2	°C. 1,050 1,150 1,150 1,250 1,350	% 2.8 4.5 10.4 16.2	% 40.3 35.5 17.0 12.6	p.w. p.w. p.w. p.w.	..... ..... Incipient	Analysis No. 30.
Class IA. (b)—											
9	Caperup Loc. 3198	Ball clay (refractory)	C.S. 88.6 — 90 1.6 — 60 1.7 + 60 8.1	75	9.2	1,050 1,150 1,250 1,350	2.7 4.7 11.7 11.8	28.6 25.2 12.0 9.8	p.w. p.w. p.w. cr. w.	..... ..... ..... Incipient	
10	Clackline, adjacent Loc. 19453	Fireclay	C.S. 84.9 — 90 14.0 — 60 .8 + 60 .3	22	8.2	1,050 1,150 1,250 1,350	5.0 4.7 8.5 15.1	42.7 41.9 33.1 19.7	p.w. p.w. p.w. g.w.	..... ..... ..... Incipient	Specked at 1,350°.
11	Collie, C.M.L. 245	Ball clay	C.S. 81.9 — 90 17.6 — 60 .4 + 60 .1	64	7.2	1,050 1,150 1,250 1,350	3.2 5.4 7.6 10.0	25.4 20.8 18.1 12.2	p.w. p.w. p.w. cr.w.	..... ..... Incipient.	
12	Goomalling Loc. 17248	Fireclay	C.S. 82.7 — 90 12.7 — 60 1.4 + 60 3.2	30	4.2	1,050 1,150 1,250 1,350	3.5 3.8 7.2 9.0	38.4 37.3 29.9 25.5	p.w. p.w. g.w. g.w.	..... ..... No vitrification	
13	Juniperding, Yimindig Creek	Fireclay	C.S. 80.7 — 90 16.9 — 60 2.3 + 60 .1	?	3.9	1,050 1,150 ..... .....	..... 5.0 ..... .....	..... ..... ..... .....	..... p.w. ..... .....	..... ..... ..... .....
14	Mokine, Loc. 4185	Fireclay	C.S. 87.3 — 90 11.3 — 60 .4 + 60 1.0	26	6.2	1,050 1,150 1,250 1,350	4.1 4.3 7.0 12.3	41.4 40.5 34.0 24.0	p.w. p.w. p.w. g.w.	..... ..... ..... Incipient	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
<i>Class 1A. (b)—continued.</i>											
15	Paddington, adjacent Rail- way Station	Semi-ball	C.S. 80.8 — 90 18.4 — 60 1 + 60 .7	34	% 1.5	° C. 1,050 1,150	% 1.4	% 15.2 .....	..... p.w. .....	.....
16	Piawaning, Loc. ?	Semi-ball	C.S. 89.4 — 90 10.2 — 60 .1 + 60 .3	50	8.9	1,050 1,150 1,250 1,350	2.7 5.2 13.3 15.0	31.0 26.0 10.7 8.1	p.w. p.w. g.w. g.w.	..... Incipient	
17	Wagin, Loc. 3533	Semi-ball	C.S. 89.5 — 90 9.5 — 60 .2 + 60 .8	30	3.7	1,050 1,150 1,250 1,350	3.4 4.3 9.7 14.7	37.1 34.6 24.0 14.5	p.w. p.w. p.w. g.w.	..... ..... Incipient	
18	Westonia, Gold P.A. 3356	Semi-ball fireclay	C.S. 80.2 — 90 16.6 — 60 1.0 + 60 2.2	46	4.7	1,050 1,150 1,250 1,350	2.8 4.6 7.6 9.4	38.0 33.8 27.5 23.3	p.w. p.w. g.w. g.w.	..... ..... No vitrification	
<i>Class 1A. (c)—</i>											
19	Holland Soak—Two miles South of	Fireclay	C.S. 72.3 — 90 23.0 — 60 1.3 + 60 3.4	20	1.4	1,050 1,150 1,250 1,350	3.5 3.8 6.2 7.7	42.8 42.2 35.3 32.6	p.w. p.w. p.w. p.w.	..... ..... No vitn. at 1,350°	Highly refractory.
20	Kalgoorlie, Gold P.A. 902	Fluxing (Cornish stone)	C.S. 72.5 — 90 21.8 — 60 3.4 + 60 2.3	14	2.6	1,050 1,150 1,250 1,350	<i>nil</i> 7.4	29.1 14.0	p.w. p.w. p.w. p.w.	..... Advanced	Analysis No. 36.
21	Kalgoorlie, P.A. 902	Fluxing (Cornish stone)	C.S. 75.9 — 90 15.9 — 60 2.4 + 60 5.8	14	2.1	1,050 1,150 1,250 1,350	..... 3.0 3.6 7.2	..... 17.5 18.9 10.5	..... p.w. p.w. p.w.	..... Incipient Advanced	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IA. (c)— <i>continued</i> .											
22	Kalgoorlie, P.A. 902	Fluxing (Cornish stone)	C.S. 72.8 — 90 25.9 — 60 .8 + 60 .5	14	% 2.1	°C. 1,050 1,150 1,250 1,350	% 1.3 3.8 9.9	% 22.4 20.1 6.6	p.w. p.w. p.w.	..... ..... Incipient Advanced	
23	Wilga, Coal P.A. 263	Refractory semi-ball	C.S. 76.1 — 90 19.0 — 60 4.1 + 60 .8	54	7.4	1,050 1,150 1,250 1,350	.4 3.2 6.9 8.4	30.8 29.3 21.6 16.6	p.w. p.w. p.w. g.w.	..... ..... ..... No vitn. at 1,350°	Analysis No. 33.
24	(Class IA. (d) and (e)— Burabadji, adjoining Loc. 7807	China clay	C.S. Fine- — 90 grained — 60 but not + 60 friable	12	3.9	1,050 1,150 1,250 1,350	3.9 6.0 11.9 15.6	39.0 34.2 21.0 12.1	p.w. p.w. p.w. w. spotted	..... ..... Incipient	Requires grinding. Analysis No. 5.
25	Collie, Premier C.M.	Semi-ball clay	C.S. 67.9 — 90 30.8 — 60 .3 + 60 1.0	50	8.1	1,050 1,150 1,250 1,350	2.6 3.5 13.2 14.4	32.1 31.3 13.2 10.2	p.w. p.w. lt. cr. lt. cr.	..... ..... Incipient	
26	Collie, Loc. 1382	Siliceous fireclay	C.S. 48.3 — 90 42.1 — 60 2.5 + 60 7.1	24	3.6	1,050 1,150 1,250 1,350	.2 .3 1.4 1.5	22.1 21.5 19.1 18.1	p.w. p.w. c.w. c.w.	..... ..... ..... No vitn. at 1,350°	Flint substitute.
27	Dangin Loc. 13096	Fireclay	C.S. 67.1 — 90 31.0 — 60 1.0 + 60 .9	39	5.4	1,050 1,150 1,250 1,350	3.1 4.4 12.3 14.5	45.0 43.4 26.7 20.9	p.w. p.w. g.w. g.w.	..... ..... ..... Incipient	
28	Ferguson, Loc. 1983	Semi-ball	C.S. 54.2 — 90 44.2 — 60 .7 + 60 .9	40	4.2	1,050 1,150 1,250 1,350	<i>nil</i> .5 2.0 2.8	22.8 23.4 21.2 18.8	p.w. p.w. cr.w. cr.w.	..... ..... ..... Incipient	Flint substitute.

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IA, (d) and (e)—											
29	Quairading, Loc. 11008	Semi-refractory	C.S., 54.7 — 90 38.1 — 60 1.4 + 60 5.8	34	% 2.8	°C. 1,050 1,150 1,150 1,250 1,350	% 3.1 3.4 12.1 13.2	% 32.8 31.3 15.6 11.5	p.w. p.w. cr.w. cr.w.	..... Incipient	
Class IB, (a)—											
30	Kanowna, P.A. 506	Semi-ball refractory	C.S., 84.8 — 90 2.5 — 60 6.8 + 60 5.9	40	3.6	1,050 1,150 1,250 1,350	.1 .3 5.1	31.2 31.5 12.4	p.w. p.w. p.w. .....	..... ..... Incipient at 1,300°	
Class IB, (b)—											
31	Cardup, West of Brickworks	Ball clay	C.S., 71.4 — 90 14.1 — 60 2.3 + 60 12.2	60	9.5	1,050 1,150 1,250 1,350	3.3 4.4 9.5 11.5	31.1 29.2 18.2 12.9	p.w. p.w. cr.w. cr.w.	..... Incipient	
32	Kalamunda, Piesse Gully	Fireclay	C.S., 73.3 — 90 11.9 — 60 7.9 + 60 6.9	40	7.9	1,050 1,150 1,250 1,350	..... ..... ..... 12.7	..... ..... ..... 9.7	..... ..... ..... p.w.	..... ..... Incipient	
Class IB, (c)—											
33	Cunderdin—Nine miles South- East of	Fireclay	C.S., 66.5 — 90 22.5 — 60 5.7 + 60 5.3	22	3.8	1,050 1,150 1,250 1,350	4.0 4.7 9.3 12.8	48.1 47.2 35.2 28.2	p.w. p.w. p.w. p.w.	..... ..... No vitn. at 1,350°	Yields good china clay by levigation.
34	Pingelly, West Brook	Plastic Fireclay	C.S., 67.8 — 90 19.6 — 60 7.8 + 60 4.8	54	2.8	1,050 1,150 1,250 1,350	2.3 5.3 12.2 16.2	42.2 35.3 19.5 12.8	p.w. p.w. g.w. g.w.	..... ..... Incipient	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—continued.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IC. (d)—											
35	Jacob's Well, Loc.	Fireclay	C.S. 68.1 — 90 11.1 — 60 9.2 + 60 11.6	25	% 6.8	°C. 1,050 1,150 1,250 1,350	% 3.2 6.8 6.4 12.1	% 38.5 31.5 29.5 17.0	p.w. p.w. ct.w. ct.w.	.... .... .... Incipient	Analysis No. 21.
Class IIA. (a)—											
36	Arncliffe, Loc. 88 and 91	Semi-ball	C.S. 90.7 — 90 5.4 — 60 .8 + 60 3.1	53	8.9	1,050 1,150 1,250 1,350	4.5 5.6 8.6 12.2	39.4 30.9 24.3 16.3	g.w. g.w. g.w. ct.w.	.... .... Incipient	Kaolin vermicular.
37	Balkaling, Loc. 11008	Semi-ball	C.S. 90.1 — 90 7.4 — 60 .6 + 60 1.9	46	7.6	1,050 1,150 1,250 1,350	2.2 3.1 9.1 13.3	37.4 34.1 20.5 11.8	g.w. g.w. ct.w. ct.w.	.... .... Incipient	
38	Balla-Balla—One mile from wharf	Refractory semi-ball	C.S. 99.0 — 90 .1 — 60 .1 + 60 .8	50	5.8	1,050 1,150 1,250 1,350	.... 1.7 5.2 4.3	.... 37.2 26.8 27.1	.... g.w. ct.w. ct.w.	.... .... .... No vitn. at 1,350°	
39	Bolgart, Lot No. 7	Ball clay	C.S. 94.4 — 90 1.4 — 60 1.4 + 60 2.8	73	11.1	1,050 1,150 1,250 1,350	5.4 5.0 10.9 16.8	30.7 31.6 19.1 6.2	p.w. p.w. g.w. ft.ct.	.... .... Incipient	Analysis No. 4.
40	Brookton, Loc. 10138	Semi-ball	C.S. 98.3 — 90 .2 — 60 .1 + 60 1.4	65	7.9	1,050 1,150 1,250 1,350	6.6 7.0 11.5 15.2	25.5 24.4 15.1 8.3	g.w. g.w. ct.w. ct.w.	.... Incipient	
41	Coolgardie, G.M.L. 2173	China clay refractory	C.S. 96.8 — 90 .5 — 60 1.6 + 60 1.1	25	2.8	1,050 1,150 1,250 1,350	3.1 4.8 7.5 7.7	37.3 38.8 30.5 28.3	g.w. g.w. g.w. ct.w.	.... .... .... No vitn. at 1,350°	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIA. (a)— <i>continued</i> .											
42	Elgin, Loc. 234	Ball clay	C.S., 92.4 — 90 6.0 — 60 1.3 + 60 .3	75	% 11.8	° C. 1,050 1,150 1,250 1,350	% 2.9 4.0 13.1 13.5	% 24.2 22.6 5.2 4.3	p.w. g.w. cr.w. cream	Incipient Advanced	Analysis No. 17.
43	Glen Forrest, Statham's Pit	China clay refractory	C.S., 96.9 — 90 1.2 — 60 1.1 + 60 .8	25	4.5	1,050 1,150 1,250 1,350	3.0 3.8 6.0 10.0	37.1 36.7 29.6 22.7	g.w. g.w. cr.w. H.cr.	Incipient Incipient	Analysis No. 19.
44	Glen Forrest	Semi-ball	C.S., 98.3 — 90 .5 — 60 .9 + 60 .3	60	9.2	1,050 1,150 1,250 1,350	4.6 8.9 14.4 16.5	34.5 22.5 12.3 8.4	g.w. g.w. g.w. cream	Incipient Incipient	
45	Goonalling, Stink Well	Semi-ball	C.S., 95.1 — 90 4.3 — 60 .1 + 60 .5	59	8.3	1,050 1,150 1,250 1,350	3.9 7.3 14.4 15.9	28.1 20.1 8.7 5.7	g.w. g.w. cr.w. cr.w.	Incipient Incipient	Analysis No. 20.
46	Goonalling, Stink Well	Ball	C.S., 94.3 — 90 4.5 — 60 .2 + 60 1.0	75	8.6	1,050 1,150 1,250 1,350	4.4 7.0 14.1 15.1	24.5 19.0 4.9 3.9	p.w. g.w. cream cream	Incipient Advanced	
47	Mt. Kokeby, Loc. 16114	Semi-ball	C.S., 91.9 — 90 7.9 — 60 .2 + 60 tr.	57	5.3	1,050 1,150 1,250 1,350	2.8 5.6 9.7 11.3	29.1 24.1 15.7 12.2	g.w. g.w. g.w. cr.w.	Incipient Incipient	
48	Mt. Kokeby, Loc. 16114	Semi-ball	C.S., 98.2 — 90 1.7 — 60 nil + 60 .1	54	14.6	1,050 1,150 1,250 1,350	5.0 7.6 15.1 19.0	35.5 31.3 14.7 6.9	g.w. g.w. cr.w. cream	Incipient Incipient	
49	Youraling, Loc. 7454	Semi-ball	C.S., 92.8 — 90 6.1 — 60 .1 + 60 1.0	50	9.5	1,050 1,150 1,250 1,350	2.7 8.6 9.7 16.3	31.2 20.6 13.9 6.9	p.w. g.w. cr.w. cream	Incipient Incipient	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIA. (b)—											
50	Collie, between C. and Wel- lington Mills	Ball Stoneware	C.S., 83.5 — 90 6.8 — 60 1.3 + 60 3.4	80	% 7.5	°C. 1,050 1,150 1,250 1,350	% 3.6 5.5 14.3 16.7	% 30.6 26.0 9.1 5.1	g.w. g.w. cr.w. cr.w.	..... ..... Incipient Advanced	
51	Duranillin	Ball	C.S., 83.2 — 90 16.0 — 60 .5 + 60 .3	98	9.6	1,050 1,150 1,250 1,350	3.9 6.6 11.5 14.9	30.4 25.1 13.9 11.4	g.w. g.w. cr.w. cream	..... ..... Incipient	
52	Dwellingup, Loc. 1121	Semi-ball	C.S., 83.4 — 90 12.3 — 60 1.6 + 60 2.7	48	9.8	1,050 1,150 1,250 1,350	3.7 4.3 13.3 13.6	37.9 34.5 18.3 17.8	g.w. g.w. cr.w. cr.w.	..... ..... Incipient	Black Spots.
53	Goomalling, Stink Well	Semi-ball	C.S., 84.9 — 90 12.7 — 60 2.3 + 60 .1	66	5.0	1,050 1,150 1,250 1,350	1.5 5.5 6.7 9.2	26.0 19.0 15.5 11.9	p.w. g.w. cr.w. lt. grey	..... Incipient	
54	Jimperding, Yimindig Creek	Fireclay	C.S., 85.5 — 90 14.3 — 60 .1 + 60 .1	28	4.7	1,050 1,150 1,250 1,350	4.9 5.2 7.3 12.7	38.9 38.3 33.5 21.9	g.w. g.w. p.w. p.w.	..... ..... Incipient	
55	Kalamunda, Piesse Gully	Fireclay	C.S., 89.7 — 90 7.4 — 60 1.4 + 60 1.5	40	7.6	1,050 1,150 1,250 1,350	3.4 3.3 6.5 10.6	29.5 25.3 20.7 14.8	g.w. g.w. cr.w. cr.w.	..... ..... Incipient	
56	Kalgoorlie, G.M.L. 350	Stoneware stone	C.S., 83.5 — 90 8.0 — 60 3.2 + 60 5.3	73	2.6	1,050 1,150 1,250 1,350	3.0 5.1 7.6 14.1	27.4 18.3 10.2 4.1	g.w. g.w. cr.w. gt.w.	..... ..... Incipient Advanced	
57	Kalgoorlie, Adj. G.M.L. 3391	Fireclay	C.S., 89.0 — 90 5.9 — 60 1.7 + 60 3.4	31	5.3	1,050 1,150 1,250 1,350	.5 2.8 7.0 11.4	34.8 27.2 21.9 11.6	p.w. g.w. cr.w. cr.w.	..... ..... Incipient Incipient	

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—continued.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIA. (b)—continued.											
58	Kalgoorlie—Seven North of	Stoneware	C.S. 83.0 — 90 17.0 + 60 <i>nil</i>	9	% 1.1	°C. 1,050 1,150 1,250 1,350	% Nil 2.6 11.0 11.2	% 24.5 18.8 2.5 .9	g.w. g.w. grey grey	Incipient Advanced	" Grit," mostly mica.
59	Kanowna, M.C. 6	Stoneware stone	C.S. 88.2 — 90 11.6 + 60 .1	4	0.7	1,050 1,150 1,250 1,350	.2 5.6 16.5 16.7	n.d. 21.1 .8 .5	p.w. g.w. gr.w. cr.w.	Incipient (1,200°) Advanced	" Grit," mostly mica.
60	Kanowna, M.C. 10	Stoneware stone	C.S. 88.1 — 90 11.1 + 60 .2 + 60 .6	9	2.7	1,050 1,150 1,250 1,350	4† 3.3 10.1 14.7	34.8 26.8 13.2 1.0	g.w. g.w. cr.w. cr.w.	Incipient Advanced	" Grit," mostly mica.
61	Kojonup	Semi-ball	C.S. 87.7 — 90 8.8 + 60 1.4 + 60 2.1	62	11.5	1,050 1,150 1,250 1,350	4.5 6.0 13.0 14.7	32.4 30.2 15.3 12.1	g.w. g.w. cr.w. cr.w.	Incipient	
62	Mt. Hardy	Fireclay	C.S. 85.4 — 90 14.6 + 60 tr. + 60 <i>nil</i>	36	5.3	1,050 1,150 1,250 1,350	3.6 4.9 12.5 15.9	38.7 35.7 20.4 13.5	g.w. g.w. cr.w. cream	Incipient	
Class IIA. (c)—											
63	Busselton—Fourteen South-East of	Ball clay or Fullers' earth	C.S. 71.9 — 90 26.5 + 60 .8 + 60 .8	154	14.9	1,050 1,150 1,250 1,350	4.9 9.0 12.7 15.2	42.8 32.7 21.9 18.5	g.w. g.w. cr.w. cream	Incipient	Refractory.
64	Collie-Cardiff Lot 283	Semi-ball	C.S. 77.3 — 90 17.7 + 60 1.8 + 60 3.2	53	6.2	1,050 1,150 1,250 1,350	.7 3.4 6.9 7.2	24.1 20.3 14.1 13.4	g.w. g.w. cr.w. cr.w.	Incipient	Refractory.

† Increase.

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
<i>Class IIIA. (c)—continued.</i>											
65	Gutha Loc. 5523	Firedlay	C.S. 70.2 — 90 26.7 — 60 .5 + 60 2.6	22	4.7	1,050 1,150 1,250 1,350	1.7 4.4 6.4 7.8	59.2 32.2 27.2 24.5	g.w. g.w. g.w. g.w.	..... ..... ..... No vit. at 1,350°	
66	Mt. Helena, 2½ miles from Railway Station	Ball clay stoneware	C.S. 77.3 — 90 21.3 — 60 1.1 + 60 .3	100	8.6	1,050 1,150 1,250 1,350	5.3 8.9 15.6 19.0	24.0 18.2 4.1 1.3	g.w. g.w. g.w. grey w.	..... Incipient 1,200° Advanced	Partly levigated from granitic clay.
<i>Class IIIB. (a)—</i>											
67	Kalamundia, Piesse Gully	Firedlay	C.S. 80.8 — 90 6.9 — 60 6.3 + 60 6.0	40	7.6	1,050 1,150 1,250 1,350	3.4 3.3 6.5 10.6	29.5 25.3 20.7 14.8	g.w. g.w. g.w. g.w.	..... Incipient	
68	Kanowna M.L. 47	Stoneware	C.S. 81.8 — 90 .8 — 60 1.8 + 60 15.6	8	0.8	1,050 1,150 1,250 1,350	.5 2.2 9.6 13.3	33.7 25.4 14.9 4.1	g.w. g.w. g.w. lt. gr.	..... ..... Incipient Advanced	
69	Kendenup Lake bed	Coarse Semi-ball clay	C.S. 81.8 — 90 2.4 — 60 3.2 + 60 12.6	40	9.5	1,050 1,150 1,250 1,350	2.6	31.6	g.w. ..... ..... .....	..... ..... ..... .....
<i>Class IIIA. (a)—</i>											
70	Beverley, East, Loc. 5784	Firedlay	C.S. 96.1 — 90 1.4 — 60 2.0 + 60 .5	23	10.5	1,050 1,150 1,250 1,350	3.9 7.6 7.7 12.3	34.6 24.0 24.0 16.6	g.w. g.w. g.w. g.w.	..... ..... ..... Incipient	
71	Cardup Lot 47/244	Ball	C.S. 93.3 — 90 2.3 — 60 1.9 + 60 2.5	76	13.2	1,050 1,150 1,250 1,350	3.3 3.3 9.2 9.6	35.6 34.8 22.1 19.7	g.w. g.w. g.w. g.w.	..... Incipient	Analysis No. 9.

APPENDIX IV.—PHYSICAL TESTS OF BEST WESTERN AUSTRALIAN CLAYS—*continued*.

No.	Source.	Type.	Texture.	Plasti- city.	Air Shrink- age.	Tem- pera- ture.	Fire Shrink- age.	Porosity.	Colour.	Vitrification.	Remarks.
Class IIIA. (a)—											
72	Capercup—Seven miles South of	Ball	C.S., 92.1 — 90 .5 — 60 .4 + 60 7.0	92	% 11.2	°C. 1,050 1,150 1,250 1,350	% 3.5 4.3 10.1 10.7	% 24.9 22.5 14.5 11.7	g.w. cr. w. cr.w. cr.w.	Incipient	
73	Collie C.M.L. 245	Firedlay	C.S., 93.6 — 90 5.3 — 60 .3 + 60 .8	14	5.3	1,050 1,150 1,200 1,250	1.1 3.9 7.7 9.7	34.4 29.5 21.3 18.2	lt. pink cr.w. cr.w. cr.w.	.... .... .... ....
74	Kalamunda-Woodlupine Brook	Ball stoneware	C.S., 90.0 — 90 7.7 — 60 .9 + 60 1.4	104	14.9	1,050 1,150 1,250 1,350	3.1 7.8 16.3 16.9	29.6 21.3 6.3 4.5	g.w. cr.w. pale grey pale grey	Incipient Advanced	Analysis No. 22.
75	Kalgoorlie, half-mile North- West of Central Battery	Stoneware	C.S., 96.8 — 90 3.0 — 60 .2 + 60 nil	Nil	1.8	1,050 1,150 1,250 1,350	3.5 9.6 17.3 18.9	33.7 17.0 1.9 1.0	cr.w. cr.w. lt. grey lt. buff	Incipient Advanced	Analysis No. 37.
76	Kanowna P.A. 506	Stoneware	C.S., 95.8 — 90 2.1 — 60 1.6 + 60 .5	3	2.6	1,050 1,150 1,250 1,350	nil 8.1 13.6 11.3	26.6 12.3 1.1 0.7	p.w. cr.w. g.w. g.w.	Incipient Advanced	
77	Manjinup Loc. 48/2034	Semi-ball	C.S., 92.4 — 90 5.4 — 60 .7 + 60 1.5	54	11.8	1,050 1,150 1,250 1,350	4.5 4.7 17.4 17.4	38.9 37.6 11.9 10.1	cr.w. cr.w. buff buff	.... .... Incipient	
78	Piawaning Loc. 39	Semi-ball	C.S., 92.9 — 90 7.1 — 60 nil + 60 nil	47	7.3	1,050 1,150 1,250 1,350	3.5 5.1 13.1 15.7	30.1 24.1 12.9 7.9	g.w. cr.w. cr.w. cr.w.	Incipient	